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THE ORIGIN OF BEACH CUSPS

In the April-May 1900 number of this JOURNAL, p. 237, Mark S. W. Jefferson has an interesting article upon "Beach Cusps.' I have often noticed these peculiar beach forms and was for some time puzzled to know how they were produced. The explanation offered by Mr. Jefferson for those on the Lynn Beach, Massachusetts, is that they "must be ascribed to the agency of the seaweed piled up on the beach, modifying the action of the greater waves." The attention I have been able to give the subject leads me to the conclusion that beach cusps are formed by the interference of two sets of waves of translation upon the beach. I know of no peculiarities of these cusps that are not explained by this theory of their origin. It will be understood by reference to the accompanying diagram, Fig. 1. The concentric lines represent two sets of waves advancing on the beach in the directions indicated by the arrows and crossing each other along the broken lines. In deep water these are waves of oscillation, but when they reach the shallow water on the beach they become waves of translation and interfere with each other where they converge upon the shore. The tendency is for them to check each other along these lines of interference and to heap up the sands at the points marked A, where they strike the beach. At the points marked B the waves diverge

and throw the beach sands and all floating material alternately right and left.

In the diagram the waves are represented as being equal distances apart, the shore has a regular curve and the cusps are

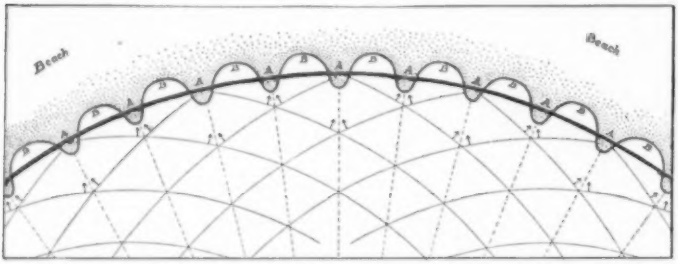


FIG. 1.—Diagram illustrating the formation of beach cusps. The concentric lines represent two sets of wave crests. The heavy line is the curve of a beach which, with these waves, would yield cusps of uniform size.

uniformly spaced. Such regularity is not to be expected in nature. The waves are not so evenly spaced, the depth of the water varies near the shore, and the waves do not all strike the shore at the same angle.

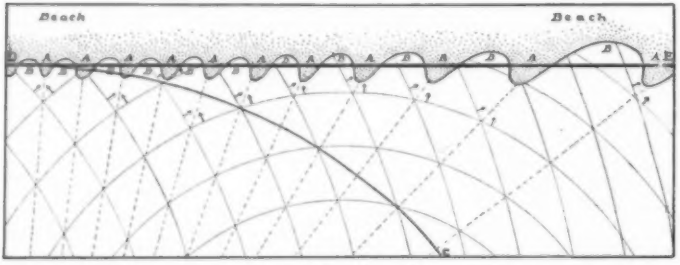


FIG. 2.—Diagram illustrating the formation of cusps of different sizes upon a straight beach D E. If D C were the beach line, these waves would produce cusps of uniform size.

In Fig. 2 the waves are represented as breaking upon a straight beach. If the water off shore were of a uniform depth and the waves were evenly spaced the cusps in this case would, for obvious reasons, be further and further apart from left to

right, as shown along the beach D E. The distance between the cusps is equal to the spaces, measured on the beach, between the radii along which the wave interference approaches the shore.

It is noticeable in California that the cusps are not permanent features of a given beach, but that they are sometimes very pronounced, at others but feebly developed, and at still others altogether obliterated or scarcely perceptible. The accompanying illustration (Fig. 3) is made from a photograph taken by the

FIG. 3.—Cusps on the beach at Santa Cruz, Cal. From a photograph taken from the Sea Beach Hotel, June 14, 1900.

writer June 14, 1900, from the Sea Beach Hotel at Santa Cruz. These particular cusps were 60, 69, 78, and 81 feet apart. They are not always visible on that beach, however. The beach of Half Moon Bay, twenty-five miles south of San Francisco, is sometimes perfectly smooth and sometimes beautifully notched. These variations are due to the changes of the relations of the waves to each other, and of the relations of the radii of the points of interference to the beach (if there are still two sets of waves). It is evident that a variation in the depth of the water off shore would retard or hasten the advance of the waves, and would consequently produce a variation in the direction of these radii and of the distance between the cusps on the beach.

On the northeast coast of Brazil I have observed cusps of remarkable height. These were, however, invariably where the water off shore was deeper and the waves broke with more than usual violence upon the beach.

I am not sure that I know how the two sets of waves referred to in this hypothesis are produced, but I am confident that they do sometimes exist, for I have seen them. It seems possible that they may be formed by an abrupt change of the wind. The concentric form is given them by their entering a bay around a headland. In one case the waves entering a broad-mouthed bay seemed to make two sets on shore by breaking around an island in the middle of the bay's mouth. It is evident that the mathematics of the work of two sets of waves might be considerably enlarged upon, but this is sufficient to call attention to the subject. That seaweeds have nothing to do with the matter is shown by the fact that at several of the places where these phenomena occur there are no seaweeds or other "drift" on the beach.

J. C. BRANNER.

STANFORD UNIVERSITY, CALIFORNIA,
August 10, 1900.

A CONTRIBUTION TO THE NATURAL HISTORY OF MARL.[1]

BOTANISTS have long been familiar with the fact that, in some regions, aquatic plants of all, or nearly all, types are covered with a more or less copious coating of mineral matter, while in other localities the same types of plant life are free from any trace of such covering. In New England, for example, plants growing in the water are generally without such coating, while in Michigan and adjoining states it is generally present. In many lakes and streams the mineral deposit on the stems and leaves of the higher plants is very noticeable, and nearly all vegetation growing in the water is manifestly an agent of precipitation of mineral matter.

Various writers in Europe[2] and America[3] have called attention to the influence of the low types of plants growing in and around hot springs and mineral springs, on the formation of silicious sinter, calcareous tufa, and other characteristic deposits of such springs, and the connection between the beds of calcareous tufa which are sometimes formed about ordinary seepage springs whose waters carry considerable calcareous matter in solution and certain species of moss has been suggested, but so far as the writer knows, no one has given attention to the possible relation of vegetation to the more or less extensive beds of the so-called marl, found about, and in, many of the small lakes in Michigan and the adjacent states. As has been pointed out elsewhere, "Marl" is made up principally of nearly pure calcium carbonate, "carbonate of lime," with greater or less admixture of impurities. When dry and pure, it is white or

[1] Printed by permission of ALFRED C. LANE, State Geologist of Michigan.

[2] COHN: Die Algen des Karlsbader Sprudels, mit Rücksicht auf die Bildung des Sprudel Sinters: Abhandl. der Schles. Gesell., pt. 2, Nat., 1862, p. 35.

[3] WEED: Formation of Travertine and Silicious Sinter by the Vegetation of Hot Springs. U. S. Geol. Surv., IX, Ann. Rept., p. 619, 1889.

slightly cream colored, coarsely granular to finely powdery, very loosely coherent and effervescing freely in acids. On dissolving it particles of vegetable and other organic and insoluble matter are found scattered through the solution.

The ultimate source of this material, except the vegetable matter, is, undoubtedly, the clays of glacial deposits and like disintegrated rock-masses. These clays are rich in finely divided limestone and in the softer rock-forming minerals, some of which contain calcium compounds. Percolating water, containing dissolved carbon dioxide, the so-called carbonic acid gas, readily dissolves the calcium and other metallic salts up to a certain limit. The water with the dissolved matter in it runs along underground until an outlet is reached and issues in the form of a spring. This, in turn, uniting with other springs forms a stream which runs into a lake, carrying along with it the greater part of its mineral load. If the amount of carbon dioxide contained in the water is considerable, some of it will escape on reaching the surface, because of decrease of pressure, and with its escape, if the saturation point for the dissolved mineral matter has been reached, a part of this matter must be dropped in the form of a fine powder, as the water runs along over the surface. Theoretically, then, some, if not a great part of the dissolved matter, should be thrown down along the courses of the streams which connect the original outlets of the water from calcareous clays and lakes where marl occurs, and we should find the marl occurring in small deposits along these streams wherever there is slack water. Moreover, we should expect the waters of these springs and streams to show more or less milkiness on standing exposed to the normal pressure of the atmosphere at usual temperatures. Actually, however, none of these phenomena have been noted, and we infer that there is not a large amount of calcium dioxide, and not an approach to the saturation point for calcium bicarbonate, in the springs and streams feeding marly lakes.

We are then left, among others, the following alternatives, explanatory of marl formation: (1) The marl is not being

formed under existing conditions, but has been formed in some previous time when conditions were not the same as now. (2) The amount of dissolved salts is so small that the saturation point is not approached until after the lakes are reached and the slow evaporation and the reduction of the amount of dissolved carbon dioxide in the water brings about deposition of the mineral salts. (3) Some other cause, or causes, than the simple release from the water of the solvent carbon dioxide must be sought.

The first of these suggestions is met by the fact that marl is found in lakes at and below the present level of the water, and that it extends in most of them to, or even beyond, the very edge of the marshes around the lakes, and over the bottom in shallow parts of living lakes, even coating pebbles and living shells. (2) The water of lakes with swift flowing and extensive outlets, such as most of our marly lakes have, is changed so rapidly that little if any concentration of a given volume of water would occur while it was in the lake, and there is no probability that any of the lakes visited by the writer have ever been without an outlet. Indeed, many of them have outlets which occupy valleys which have been the channels of much larger streams than the present ones. Moreover, definite measurements which, however, are subject to further investigation, have been made, which show that the volume of water flowing out of these lakes is practically the same as that flowing into them, *i. e.*, the loss by evaporation is too small a factor to be taken into account. Farther, recent investigations[1] have shown that calcium, as the bicarbonate, is soluble to the extent of 238 parts in a million, in water containing no carbon dioxide. As most of our natural waters, even from living clays, contain no more than this amount of salt, even when they carry considerable free carbon dioxide, and many analyses show a less amount of it, the fact becomes plain that even if the carbon dioxide were all lost there would be no precipitation from this cause. (3) Considering these objections as valid it seems

[1] TREADWELL and REUTER: Ueber die Loeslichkeit der Bikarbonate des Calciums und Magnesiums. Zeitschrift für Anorganish-Chemie, Vol. 17, 1898, p. 170.

fitting to examine into the possibility of the plant and animal organisms living in the waters of the lakes being the agents which bring about the reduction of the soluble calcium bicarbonate to the insoluble carbonate even in waters low in the amount of dissolved mineral matter, and containing considerable carbon dioxide. That mollusks can do this is shown by the fact, which has frequently come under the writer's notice, that the relatively thick and heavy shells of species living in fresh water are often partly dissolved and deeply etched by the action of carbonic acid after the animals have, by their processes of selection, fixed the calcium carbonate in their tissues, precipitating it from water so strongly acid and so free from the salt that re-solution begins almost immediately. No natural water seems so free from calcium salts that some species of mollusks are not able to find enough of the necessary mineral matter to build their characteristic shells.

While some limited and rather small deposits of marl are possibly built up, or at least largely contributed to, by molluscan and other invertebrate shells, the deposits which are proving commercially valuable in the region under consideration, do not contain recognizable shell fragments in any preponderance, although numerous nearly entire fragile shells may be readily washed or sifted from the marl. The conditions under which marl is found are such that the grinding of shells into impalpable powder, or fine mud, by strong wave action is improbable, if not impossible, for exposed shores and shallow water of considerable extent are necessary to secure such grinding action, and these are not generally found in connection with marl.

We are, then, reduced to the alternative of considering the action of plants as precipitating agents for the calcium salts. It has been shown already that plants generally become incrusted with mineral matter in our marly lakes, and it is easy to demonstrate that the greater part of the material in the incrustation is calcium carbonate. It is also easy for a casual observer to see that the deposit is not a true secretion of the plants, for it is purely external, and is easily rubbed off the outside of the plants

in flakes, while the tissues beneath show no injury from being deprived of it, and again, as has already been pointed out, the same species of plants in some sections of the country do not have any mineral matter upon them. The deposit is formed incidentally by chemical precipitation upon the surface of the plants, probably only upon the green parts, and in performance of normal and usual processes of the plant organism.

All green plants, whether aquatic or terrestrial, take in the gas, carbon dioxide, through their leaves and stems, and build the carbon atoms and part of the oxygen atoms of which the gas is composed into the new compounds of their own tissues, in the process releasing the remainder of the oxygen atoms. Admitting these facts, which are easily demonstrated by any student of plant physiology, we have two possible causes for the formation of the incrustations upon plants.

If the calcium and other salts are in excess in the water, and are held in solution by carbon dioxide, then the more or less complete abstraction of the gas from the water in direct contact with plants, causes precipitation of the salts upon the parts abstracting the gas, namely, stems and leaves. But in water containing amounts of the salts, especially of the calcium bicarbonate, so small that they would not be precipitated if there were no carbon dioxide present in the water at all, the precipitation may be considered a purely chemical problem, a solution of which may be looked for in the action upon the bicarbonates, of the oxygen set free by the plants. Of these calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the following chemical equation:

$$CaH_2(CO_3)_2 + O = H_2O + CaCO_3 + CO_2 + O \left.\begin{matrix}\text{calcium} \\ \text{bicarbonate}\end{matrix}\right\} +$$

$$\text{oxygen} = \text{water} + \left.\begin{matrix}\text{calcium} \\ \text{carbonate}\end{matrix}\right\} + \left.\begin{matrix}\text{carbon} \\ \text{dioxide}\end{matrix}\right\} + \text{oxygen},$$

in which the calcium bicarbonate is converted into the normal carbonate by the oxygen liberated by the plants, and both carbon dioxide and oxygen set free, the free oxygen possibly acting still farther to precipitate calcium monocarbonate.

It is probable that the plants actually do precipitate calcium carbonate, both by abstracting carbon dioxide from the water and by freeing oxygen, which in turn acts, while in the nascent state, upon the calcium salt and precipitates it, but in water containing relatively small amounts of calcium bicarbonate the latter would seem to be the probable method.

The calcium salt is deposited in minute crystals, and by the aggregation of these crystals the incrustation is formed on the plants. The crystals are distinguishable as such only for a short time on the newer growths of plants, but the incrustations are said to show a recognizable and characteristic crystalline structure when examined in thin section under a compound microscope with polarized light.

Not all aquatic plants in the same lake seem equally active in the precipitation of mineral matter. Not even all species of the same genera, even when growing side by side, will be coated equally, a fact which seems to indicate some selective metabolic processes not understood. Considering the precipitation of calcium carbonate by plants as established, even if the exact physiological and chemical processes by which this precipitation is brought about, are not yet worked out fully, it is still necessary to consider the constancy of the action and the sufficiency of the agency to produce the extensive deposits of marl which are known.

If one confines his studies simply to the seed-producing plants and other large vegetable forms which are conspicuous in lakes during the summer season, while he will find them covered with a thin coating of manifestly calcareous matter, he will at once be convinced that such work as these plants are doing is but a small factor in the total sedimentation of the lake. On the other hand, if a visit be made to a lake in early spring or late fall, all plants of the higher types will not be found, so that it becomes apparent that this agency is merely a seasonable one and works intermittently. Farther study of the plants of the same body of water, however, shows that the algæ, the less conspicuous and entirely submerged plant organism, must be taken

into account before we finally abandon plants as the agents of precipitation. Of these, two groups, differing widely in structure, habits, and method of precipitation, will be found. The first and most conspicuous, and probably the most important as well, is the Characeæ or Stoneworts. These plants are well known to botanists, and may readily be recognized by their jointed stems, which have at each joint a whorl of radiating branches, which are also jointed. In some species the stems and branches are covered with a thick coating of mineral matter, are almost white, and very brittle because of this covering. These plants not only grow near the surface in shallow water, where it is unoccupied by other plants, but in the deeper parts as well of our ponds and lakes, and, as they thrive where light is feeble, they continue to grow throughout the year, although in winter they must grow less rapidly than in summer, because ice and snow on the surface of the lakes make less favorable light conditions.

The sufficiency of these plants alone to fix and deposit calcium carbonate in large quantities is indicated by the following: In November 1899 the writer collected a large mass of plants of Chara sp?, from which five stems with a few branches were taken at random and without any particular care being taken to prevent the brittle branches from breaking off. The stems were each about 60^{cm} long, and after being dried for some days they were roughly ground in a mortar and dried for one half hour at 100° C., dried and weighed until the weight was constant. The weight of the total solid matter obtained in this way from five plants was 3.6504 grams, 0.73 grams per plant. This was treated with cold hydrochloric acid diluted, twenty parts of water to one of acid, filtered, washed, and the residue dried at 100° C., on a weighed filter paper, until weight was constant. The weight of insoluble matter was 0.5986 grams; of the total soluble matter 3.0518 grams, or .6103 grams per plant. In the lake from which the material analyzed was derived from 50 to 80 plants were counted to the square decimeter of surface in the Chara beds.

A partial quantitative analysis of material from the same source, but using stronger acid to affect solution (hydrochloric acid, diluted with four parts of water), gave the following results:

Insoluble residue	11.19 %
Iron and aluminum oxides	0.722
Calcium carbonate	76.00
Magnesium carbonate	2.359
Soluble organic matter obtained by difference	9.279

The composition of the insoluble residue was obtained by heating the residue to redness in a platinum crucible for one half hour, and the 11.19 per cent. of this matter was found to consist of:

Combustible and volatile matter	9.243 % = 82.6 %
Mineral matter	1.947 = 17.4

The mineral matter was found to be:

Silica	1.787 % = 92.4 %
Not determined	.160 = 7.6

Microscopic examination showed the silica to be largely composed of whole and broken tests of diatoms, minute plants which secrete silicious shells and attach themselves to the Chara stems and branches.

The mineral matter obtained in this analysis, reduced to parts per hundred, gives the following:

	Per cent.
Calcium carbonate	93.76
Magnesium carbonate	2.93
Silica and undetermined mineral matter	2.40
Iron and aluminum oxides	.89

This, with a small decrease in the mineral matter and a small amount of organic matter added, would be the composition of ordinary marls, and would be a suitable sample to consider in connection with Portland cement manufacture.

The large amount of silica may be explained by the fact that the material analyzed was collected at a season when diatoms are especially abundant.

It may be well to call attention to the fact that in many marls, especially those of large deposits, which the writer has examined

chemically, the silica has been found to be in the form of diatom shells, and hence, because of the small size and great delicacy of these structures, it is available as a source of silica for calcium silicate in cement making. If such deposits as are made up largely of diatom shells were adjacent to marl beds, it is possible they might be considered as clay and be used in cement making.

From the above considerations, it is evident that both because of the quality and quantity of its works, Chara may be considered an important agent in marl production, and it only becomes necessary to account for the chalky structure of the deposits to make the chain of evidence complete. All algæ are plants of very simple structure, without tough or complicated tissues. Chara stems and branches are made up of aggregations of thin-walled cells, and when the plants die the cell walls must rapidly decay and the residue of lime be left. In a laboratory experiment to determine this factor, it was found that a mass of the broken-up plants placed in the bottom of a tall glass vessel filled with water became decomposed very quickly, giving the characteristic odor of decaying vegetable matter, and after a few weeks all organic matter had disappeared, leaving the incrustations in tubular, very brittle, fragments. In studying the structure of marl, the writer has found that near the top of the beds there is usually a "sandy," or even a coarsely granular structure. This is noticeable, at times, at all depths from which the samples are taken, *i. e.*, in some cases it extends through the bed. Close examination of such marl shows that this coarseness is due to the remains of the characteristic Chara incrustations, and that the "sand" and other course material is made up of easily identifiable fragments of the coatings of stems and branches of the plant. The presence of such coarse matter near the top of the beds may be considered due to sorting action of the waves, and such surface currents as may be caused in ponds and small lakes, in shallow water, by wind action. If these agents are effective in producing the coarser parts of the deposits they may be also considered so in connection with the finer parts as well, for the matter

produced by the breaking and grinding up of fragments is held in suspension for a longer or shorter time, carried about by currents, and finally sinks to the bottom in the quieter and deeper parts of the lakes.

Chara may also be looked upon as an important agent in giving the peculiar distribution to marl which has been noticed by every one who has "prospected" beds of material. The fact is frequently noticed that beds of several, and even as much as twenty or more, feet in thickness will "run out" abruptly into beds of "muck," or pure vegetable débris, of equal thickness. This distribution may show that up to a certain time conditions unfavorable to the growth of Chara are favorable to other plants obtained, until a depth of water was reached at which Chara was able to occupy the bed of muck, covering it from the bottom up, and holding the steep slope of the muck in place by mechanically binding it there by its stems and the root-like bodies by which it is connected with the mud. From the time when the Chara began its occupation of the muck the amount of organic matter left would decrease, and the amount of calcareous deposit would increase, until the latter predominated. The disturbing factors of currents and waves can be disregarded, for these abrupt unions of marl and muck are found, so far as the observations of the writer go, in most sheltered places, and not where either currents or waves could ever have operated with any force or effectiveness. Moreover, in a lake where the marl is evidently now actively extending, the slope was observed to be nearly perpendicular, and the steep banks thus formed were thickly covered with growing Chara, to the exclusion of other large forms of plant life, and the lower parts of the growing stems were buried in mud which was mainly pure marl.

In regard to the species of Chara which seems to be the active agent in precipitation in the lakes of central Michigan, it is the form commonly known as *Chara fragilis*, but it is probable that careful study of the species throughout the range of the marl will reveal, not a single form, but a number of allied species, engaged in the same work. It may be well to suggest that

in lakes to which much silt is brought by inflowing streams, or which have exposed shores where the waves are constantly cutting and stirring up rock débris, the more slowly accumulating marls will be either so impure as to be worthless, or so obscured as to escape notice altogether, even where Chara is abundant. It may also be pointed out that shallow water, strong light, and a bottom of either clay, sand, or muck, present conditions favorable for the growth of the higher vascular plants, and that these cause such rapid accumulation of vegetable débris that the calcareous matter may be hidden by it, even when Chara is a well-marked feature of the life of a given lake.

Another plant form, like Chara an alga, but of a much lower type, which is concerned in the formation of marl is one of the filamentous blue-green algæ, determined by Dr. Julia W. Snow, of the University of Michigan, to be a species of Zonotrichia, or some closely related genus.

The work of this species is entirely different in its appearance from that of Chara, and at first glance would not be attributed to plants at all. It seems to have been nearly overlooked in this country at least by botanists and geologists alike, as but a single incidental reference to it has been found in American literature.[1] Curiously enough, however, material very similar, if not identical, to that under consideration has been described from Michigan in an English periodical devoted to Algæ.[2] In this the alga is identified as *Schizothrix fasciculata* Goment. As comparison of material is not possible at the present time, the plant under consideration is here tentatively called Zonotrichia. The plant grows in relatively long filaments, formed by cells growing end to end, and as they grow, the filaments become incased in calcareous sheaths. The feature of the plant which makes it important in this discussion, however, is its habit of growing in masses or colonies. The colony seems to start at some point of attachment, or on some object like a shell, and to grow outward radially in all directions, each filament independent

[1] McMillan: Minn. Plant Life, 1899, p. 41.

[2] G. Murray: Phycological Memoirs No. XIII, 1895, p. 1, Pl. XIX.

of all others and all precipitating calcium carbonate tubules. The tubules are strong enough to serve as points of attachment for other plants, and these add themselves to the little spheroid, and entangle particles of solid matter, which in turn are held by new growths of the lime-precipitating Zonotrichia, and thus a pebble of greater or less size is formed which to the casual observer is in no wise different from an ordinary water-rounded pebble. These algal calcareous pebbles show both radial and concentric structure and might well be taken for concretions formed by rolling some sticky substance over and over in the wet marl on which they occur but for the fact that a considerable number of them show eccentric radial arrangement, and that the shells of accretion are likewise much thicker on one side than on the other, and finally, because the side which rests on the bottom is usually imperfect and much less compact than the others. The pebbles are characteristically ellipsoidal in shape. The radial lines, noticeable in cross sections of the pebbles, are considered by the writer to be formed by the growth of the filaments, while the concentric lines probably represent periods of growth of the plants, either seasonal or annual. Included within the structure are great numbers of plants, besides the calcareous Zonotrichia, among them considerable numbers of diatoms, and it is probable that a large part of the algal flora of a given lake would be represented by individuals found in one of these pebbles. It is probable that to a certain extent they disintegrate after the plants cease to grow, for they are never very hard when wet. It is possible to recognize them, as lumps of coarser matter, even in very old marl, and the writer has identified them in marl from Cedar Lake, Montcalm county, Mich., which was taken from a bed a foot or more above, and several rods away from, the lake at its present level. From the fact that these pebbles have been found in four typical marl lakes in different parts of Michigan (in Zukey Lake, by Dr. A. C. Lane, who was struck with their peculiar character) and have been reported from a number of others by marl hunters, it is probable that they have a wide distribution in the state and are constant if not

important contributors to marl beds. It may be said in passing that the limy incrustations which are found upon twigs, branches, shells, and other objects in lakes and streams, and called generally "calcareous tufas," are of similar origin and are formed by nearly related, if not by the same, plants that form the pebbles.

Studies have been begun by the writer to solve, if possible, some of the questions which have arisen in connection with the statements embodied in this paper, but enough has already been done to show that these forms of fresh-water algæ are important lime-precipitating agents now, and to suggest the possibility that in all likelihood they have been more active in former geological times, and that, as has been suggested again and again by botanists, the formation of certain structureless limestones, and tufa deposits may have been due to their work.

CHARLES A. DAVIS.

ALMA COLLEGE,
September 1, 1900.

A REMARKABLE MARL LAKE[1]

EARLY in June 1900 the writer visited Littlefield Lake, Isabella county, Michigan, which, from its peculiar form, and the deposits about it, seemed worthy of special description.

The country about the lake is of a well-marked morainal structure, the till, however, being sandy in places, and noticeably gravelly and bowldery throughout, and formerly heavily covered with pine. The lake occupies a deep depression in a trough-like valley, surrounded by moderately high morainal hills, and from its apparent connection with a series of swampy valleys, suggests a glacial drainage valley, but as it was not followed for any distance its origin was not determined.

The lake itself is about one and one half miles long by three fourths of a mile broad in the widest part, which is near the middle of the long axis, and the shape is that of an irregular blunt-ended crescent. It was said to be over eighty feet deep in the deepest part, but no soundings were made by the writer. Its greatest length is from northwest to southeast, with the outlet at the southern end. There are no considerable streams entering it, but at least three small brooks, fed by springs from the surrounding hills, were noted flowing in, and the outlet is of such size that a boat may be easily floated on it at high water, although its level is maintained during the summer by a dam about two miles below the lake. The main inlet was not seen by the writer.

The shore lines are relatively regular, especially on the east and north sides, the convex side of the crescent, with banks twenty or more feet high close to the water on the east, while on the west side are two rather deeply indented bays. At either end are three small ponds, parasite or daughter-lakes, and surrounding the entire shore, except on the eastern side and the

[1]Printed by permission of Alfred C. Lane, State Geologist of Michigan.

northeastern or inlet end, is a cedar swamp which is underlaid by marl. The outlet is through the most southerly of the daughter-lakes, and the entire shore of the lake is formed by beautifully white marl, the exposures varying in width from a few feet to three or four rods in width, so that as one overlooks the lake from one of the surrounding hills it seems to lay in a basin of white marble.

There are three small islands in the lake, two relatively near together at the northern end, and one quite near the shore at the south end. These islands are also of marl, covered partly with a thin layer of vegetable matter and a scanty growth of grass, bushes, and cedar. There is a visible connection, under water, between at least one of the islands and the nearest shore, and it is probable that all of them are thus connected by submerged banks. The marl on the islands is from twenty-five to thirty feet deep, with sand below.

Explorations in the swampy border of the lake show that the shore was formerly more irregular than now, and that the marl extends back from the water in some places for at least one fourth of a mile, gradually becoming more and more shallow until the solid gravel or clay is reached. The marl is frequently thirty feet deep along the shore, and at no place was it found to be less than fifteen feet deep at the present shore line, the shallowest places being along the shore where the high bank comes down near the water. The deepest vegetable deposit, or peat, found in one hundred and fifty borings in all parts of the deposit was three feet. The main deposits of marl are about the southeast end and along the western side of the lake, with a body of considerable size underlying a swampy area at the north end. Of the six daughter-lakes four are very small, an acre or two in extent, and entirely surrounded by deep marl, the connection between three of them and the mother-lake being shallow and narrow, a few inches deep, and a few feet wide, and only existing at high water, while two of the other three are of much larger size, with marl points extending out from either side of the strait, which is still relatively wide and deep.

Of the two bays on the west side of the lake, one is much narrower than the other, and at the mouths of both, marl points are extending towards each other to a noticeable degree.

At all points along the shore the slope of the marl is very abrupt from the shallow water to the bottom, always more than 45°, and frequently nearly 90°, this steepness being noticable in the small as well as in the parent lakes, while on the east side of the island at the south end of the lake, the wall of marl seemed positively to overhang, although this appearance was probably due to refraction.

The texture of the deepest part of this marl deposit is apparently that of soft putty; a sounding rod passed through it with comparative ease, and samples brought up have a yellowish or creamy color, which disappears as they dry, leaving the color almost pure white. At the surface the marl is coarser, slightly yellowish, and more compact. Where it lies above the water line it is distinctly made up of granular and irregular angular fragments, resembling coarse sand, but the fragments are very brittle, soft, and friable, and may be converted into powder by rubbing between the thumb and fingers.

On the parts of the shores where apparently the wave action is chiefly exerted, there are small rounded calcareous pebbles, mixed with molluscan shells, drift material, and considerable quantities of stems, branches, and more or less broken fragments of the alga Chara, all parts of which are heavily incrusted with calcareous matter. This Chara material was often piled up in windrows of considerable extent at the high-water mark.

The marl banks of the lake, from a little below the water's edge down as far as could be seen, were generally thickly covered with growing Chara. At the time of the writer's visit, and wherever a plant of it was examined, it had a heavy coating of limy matter, which was so closely adherent to the plant as to seem a part of it, and because of this covering the plants were inconspicuous and would easily escape notice.

Little if any other vegetation of any character was growing in the lakes at this season; indeed, from the steep slope of the

banks of marl, it would be hardly possible for any considerable amount of vegetation of higher types than algæ to flourish here, because of the lack of light at the depth at which it would have to grow to establish itself.

As Chara of several species is known to occur within our limits at depths as great as thirty feet, and probably grows at even greater depths where the water is clear and the bottom soil is of the right character, *i. e.*, of clay, finely divided alluvial matter, marl, etc., it is apparent that there must be an immense growth of this type of plants in such a lake as the one under discussion. That there is an abundance of Chara in Littlefield Lake is shown by the amount of drift material, composed of the plant, which has accumulated in heaps at the high-water wave marks along the shore at various places.

From even a casual inspection of this drift accumulation, it is evident that it is the source of much of the granular and sand-like marl on the beaches and in the coarse upper layers of the deposit. This wind-and-wave accumulated material was dry and bleached, and was very brittle—so fragile, indeed, that a mere touch was generally sufficient to break it into fragments, and it passed by insensible gradation from the perfect, unbroken, dried plant form at the high-water mark, in which every detail, even the fruit, is preserved, to inpalpable powder at and below the water's edge.

In other words, we have in Chara, a plant of relatively simple organization, able to grow in abundance under most conditions of light and soil which are unfavorable to more highly developed types, a chief agent in gathering and rendering insoluble calcium and other mineral salts brought into the lake from the clays of the moraine around it by the stream, spring, and seepage waters. After precipitation is accomplished and the plant is dislodged or dies it drifts ashore, where, after the decomposition and drying out of the small amount of vegetable matter, the various erosive agents at work along shore break up the incrusting chalky matter, and the finer fragments are carried into deeper water, the coarser are left along the lines of wave action.

The pebbles mentioned above as occurring on parts of the shore are also the result of the development and growth of an alga, Zonotrichia or a nearly related genus, a much lower type than Chara, having a filamentous form. The vegetable origin of these pebbles would not be suspected until one recently taken from the water is broken open, when it is found to show a radiating structure of bluish-green lines, the color indicating the presence of the plants, as it is characteristic of the group to which Zonotrichia belongs.

The relation of the deposits about Littlefield Lake to the direction of the prevailing strong winds of the region is probably significant.

The area of deposition is at the southeast end and along the whole western side of the lake. The winds which would be most effective in the valley of the lake would be those from the north and northwest, which would drive the surface waters down the lake toward the southern end, and, striking the shore on the eastern side; these currents would be turned across the lake to the west, depositing sediment at the turning area and in slack water beyond. The daughter-lakes are not easily accounted for except in a general sense, that they were formerly deep bays, which, by the building out of points of marl on either side of their mouths, were finally enclosed. The tendency, already noted, for existing bays to have points of marl of spitlike form extend from either side of the mouth would seem to indicate this as a probable method of formation. On the island at the south end of the lake there was manifestly a strong current, which was running southeasterly and depositing fine marl on the east side of the island, the wind, at the time the observation was made, blowing gently from a few points north of west.

As has been already noted, the islands consist of marl from twenty-five to thirty feet deep, the bottom on which they are built up being, to judge from soundings made with an iron rod, of rather fine sand. These foundations of sand have deeper water all around them, if soundings said to have been made by local fishermen can be relied upon; so it is possible they

represent shallows in the original lake bottom, upon which, after Chara had established itself, the marl accumulated, both by direct growth of the plants and by sedimentation. It may be worthy of mention that the Chara growing on the steep banks may, in part, account for their steepness by acting as holding agents, binding the particles of sediment in place by stems and the rootlike organs which the plant sends into the mud. It is probable that but a small part of the Chara that grow in the lake ever reaches the shore wave-line, and much must break up by the purely chemical processes resulting from organic decay in relatively deep water.

CHARLES A. DAVIS.

THE ORIGIN OF THE DÉBRIS-COVERED MESAS OF BOULDER, COLORADO

At the base of the mountains south of Boulder, Colorado, is found a series of table lands, or mesas, which rise 300 to 500 feet above the bed of Boulder Creek, and which slope away from the mountains at an angle of about 3½°. Mesas of a similar nature are found at numerous points along the mountain front, some of them much more extensive than the ones of which I write. This article is the result of a study of those included between Boulder Creek and South Boulder Creek. Their location is shown in Fig. 1. A photograph (Fig. 2) shows their general aspect and their relation to the foothills. Fig. 3 is an east-west section of the mesa shown in the photograph, giving its structure. A sheet of unconsolidated fragmental material, 25 to 50 feet in thickness, rests upon the eroded surface of the upturned Cretaceous formations, principally the Fort Pierre shale. The Benton, Niobrara, and Dakota are inconspicuous at this point, owing to the proximity of the Boulder arch described by Eldridge.[1] This covering of débris forms the protecting cap of the mesas. It is composed almost wholly of sandstone and conglomerate from the Red Beds of Permo-Trias age, which formerly covered the mountain front and which still rise about 2000 feet above the level of the plains. Their serrate peaks are shown along the lower mountain front in Fig. 2. At this point the Red Beds dip at an angle of 48°. The fragments of the detrital capping vary in size from grains of sand to bowlders twenty feet in diameter. They are notably angular, bearing little evidence of long continued water action, and are very imperfectly sorted. Coarse and fine materials are bedded together in the most intimate relations. Originally they formed a continuous sheet of débris, the greater part of which has been destroyed by subsequent erosion.

[1] U. S. Geol. Surv., Mon. 27, p. 105.

The mesas are bordered by rather sharp declivities. Between the foot of these declivities and the flood plains of the creeks is an inclined surface which may be called the mesa-terrace. It is a wide shelf-like surface extending from the base of the mesas

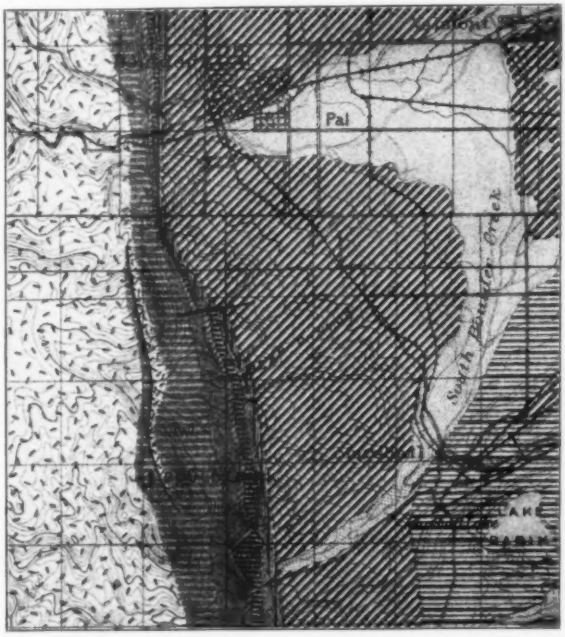


FIG. 1.—The geological formations in order from the left (west) are: (1) Crystallines of the Mountains; (2) Lower Red Beds; (3) Upper Red Beds; (4) Como (Atlantosaurus Beds); (5) Dakota; (6) Benton; (7) Niobrara; (8) Ft. Pierre and Fox Hills; (9) Laramie.

proper to the border of the present flood plains, where in some cases it is terminated by a bluff, while in others it descends in a gentle transition slope not always separable from the mesa-terrace, making one continuous incline from the base of the mesas to the border of the flood plain, into which it passes by imperceptible gradations. Where this transition slope has been

destroyed by the existing streams, and a bluff or steep slope formed, the mesa-terrace impresses one as being possibly due to a former cycle of erosion. But where the transition slope is intact and the surface of the mesa-terrace passes gently into that of the flood plain the two are seen to be obviously due to a continuous process of erosion uninterrupted by any notable change in the attitude of the land.

The substructure of the mesa-terrace is similar to that of the mesas proper, but its surface is more irregular and the covering of fragmental material is not uniform in thickness or in distribution. The mesa-terrace is shown, in part, in the middle foreground of Fig. 2 with the buildings resting upon its surface. The covering of the mesa-terrace differs from that of the mesas, first, in the thinner and more irregular nature of the sheet of débris; second, in the more rounded character of the fragments; and third, in the greater content of crystalline material. The débris on the tops of the mesas contains about 1 per cent. of crystalline material, while the débris on the mesa-terrace is made up of sandstone and crystalline material in varying proportions. The crystalline material of the mesas is chiefly quartz and metamorphic sandstone, such as is contained in the conglomerate of the Red Beds, from which it very probably came, in the main. The crystalline material on the mesa-terrace is largely granitic, and is usually much water-worn and in an advanced stage of decomposition.

At still lower levels is found the sheet of débris which is now gathering over the valley bottoms of the existing streams. These streams are forming wide bottom lands[1] which have a gradient at Boulder of about fifty feet to the mile. In this recent débris the material is imperfectly sorted and is composed largely of crystalline rock from the mountains. The fragments are well rounded and the granitic constituents are not usually decomposed.

In these three stages we find an instructive series; first, the mesa tops, composed mainly of sandstone débris of an angular, slightly worn character; second, on the mesa-terrace the mantle

[1] See Pocket Map, Mon. 27, U. S. Geol. Surv.

FIG. 2.—Photograph of the region south of Boulder, from a point north of the city. The surface of one of the mesas and the mesa-terrace appears in the horizon at the left. The point at the extreme right is the peak of Green Mountain, and that in the background is South Boulder Peak.

has proportionately less sandstone, more metamorphic, and more granitic material, the latter in a much decomposed state; and third, the recent valley drift, composed mainly of well rounded crystalline material of which undecomposed granitic rock forms a large part.

There is one other group of phenomena which must be considered before attempting an interpretation. There is a large mesa near the mouth of Bear Canyon (see map, Fig. 1) on which the largest bowlders are found in great numbers. This mesa is also the highest in the region under discussion. A line drawn from its top, parallel to the foothills and touching the tops of the mesas to the north, would have a gentle slope in that direction, *i. e.*, toward Boulder Creek. A similar though indistinct slope toward South Boulder Creek is indicated by

some remnants south of this mesa. The mesa-terrace has a corresponding inclination.

From the foregoing facts the conditions of formation may be inferred :

1. At the time the mountains began to assume their present elevation they were faced, if not covered, with the sedimentary formations whose truncated edges are now exposed along the foothills. At an early stage of erosion the young streams carried away the shales, since they lay uppermost, and formed the grade upon which the sandstone débris was deposited. The streams found little of a coarse or enduring nature with which to form a deposit and thus prevent the cutting down of the shales to a low gradient until they had cut back into the Red Beds.

2. When the erosion began to work effectively upon these, much coarse and enduring material was loosened and carried down the high gradient of the mountain flank, but the streams were unable to carry all of the coarse parts of it across the lowered gradient of the shale tract, and hence deposited it as the mantle of the present mesa tops.

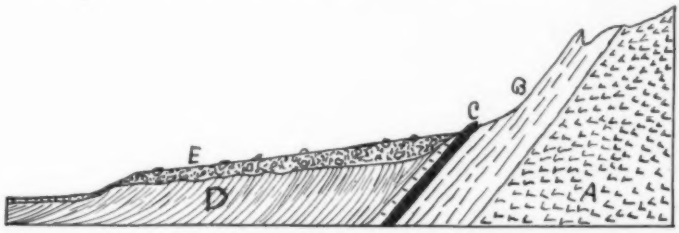
3. As the streams by headward extension reached back into the crystalline area, they derived a less relative amount of material from the Red Beds and more from the crystalline area. Besides, by reaching backward, their gradients had been reduced and they reacquired some eroding power in the mesa zone, and hence cut into it and formed the lower surface — the mesa-terrace — on which is found relatively more crystalline material and relatively less of that from the Red Beds. The granitic material of this mantle being relatively old is much decomposed.

4. The later deposits represent the process carried farther, giving a still larger proportion of crystalline débris, and this, being young, is undecomposed.

At first Bear Creek was an important stream, as shown by the wide gap between Green Mountain and South Boulder Peak. But, for reasons unexplained, Boulder Creek and South Boulder Creek, on either hand, gained in importance at its expense, and

as they more effectually lowered their channels a new grade was produced in the mesa zone, represented now by the mesa-terrace. At the same time this new grade was covered with material formed by a mingling of the old mesa-tops débris with the fresher material from the mountains.

The process of forming the grade and covering it with débris in this manner may be studied in minutest detail at the present day in Boulder Creek Valley. As the present streams are cutting away the mesa-terrace and mingling its fragmental material with



Section of formations shown in FIG. 2.

FIG. 3.

E—Fragmental débris.
D—Fort Pierre Shale.
C—Dakota.
B—Red Beds.
A—Crystallines.

the fresh material from the mountains, so the more ancient streams undermined the sheet of débris on the mesa-tops and mingled it with that of the then flood plains.

The production of the abrupt slopes forming the sides of the mesas, and to a less extent bounding the mesa-terrace on the one hand, and on the other hand the lateral inclination of the surfaces of both, is well illustrated in Boulder Creek Valley. Before issuing from the crystalline area Boulder Creek has a high gradient and little of its energy is spent in cutting sidewise. Where it passes to the shale formations at Boulder, its gradient becomes lower and much of its energy is spent in cutting laterally. The result is a comparatively slow lowering of the bed of the stream and a comparatively swift migration laterally in the shale region. The migration is at present toward the south. The city

of Boulder is built upon the ground recently abandoned by the stream. A north-south section through the city (see map, Fig. 1), cutting directly across this recently formed grade, shows a slope of the surface to the south of nearly fifty feet to the mile. The tops of the mesas and the surface of the mesa-terrace have an inclination somewhat greater than this but in the opposite direction. It is near the city of Boulder that the most conspicuous slopes are found bordering the mesa-terrace. The transition slope has been cut away and bluffs formed fifty feet high in

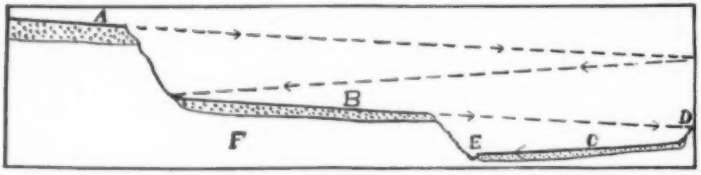


FIG. 4.—Diagrammatic section from the mesa (*A*) south of Boulder City, to the northern border of the present valley bottom, illustrating the assigned origin of the lateral inclinations of the mesa tops, mesa-terrace and valley bottom. *A*=mesa; *B*=mesa-terrace; *C*=valley bottom on which the city stands; *E*=Boulder Creek; *F*=Fort Pierre shale. The dotted lines represent the migrations of Boulder Creek together with the gradual lowering of its bed, the two processes combined producing the northward inclination of the mesa tops and the mesa-terrace, and the southward inclination of the valley bottom.

places. Should this process be continued to the extent of reducing the mesa-terrace to the lateral proportions of the mesas, the transition slopes would all disappear, and the bounding slopes of the mesa-terrace would present essentially the same aspect as those of the mesas. The probable action of the stream in producing the northern inclinations of the mesa-tops and the mesa-terrace together with their bounding slopes, and the southern inclination of the valley bottom by means of lateral migrations is illustrated in Fig. 4.

It is quite impossible to say what influence, if any, surface movement has had in changing the inclinations of the surfaces or determining special features. It seems, however, unnecessary to appeal to such movement, since the phenomena may be

rationally explained by such processes of erosion and deposition as may be witnessed in the same region at the present time.

Conclusions.— From the phenomena observed in this region four conclusions may be drawn: (1) That the accumulations of débris forming the protecting surface of the mesas and the mesa-terrace are of fluviatile origin, and that in their mode of accumulation they differ in no essential respect from that in action over the valley bottoms in that vicinity at the present day. (2) That the mesa tops mark the level of a grade formed by the young streams soon after the adjacent mountains had assumed something like their present attitude. (3) That the three grades represented by (*a*) the mesa tops, (*b*) the mesa-terrace, and (*c*) the present valley bottoms do not seem necessarily to require the assumption of any change in the attitude of the land subsequent to the elevation of the mountains, but are the natural sequences of erosion as influenced by the local distribution and difference in hardness of the formations involved. (4) That the grades were formed and covered with débris by the streams at essentially the same time, and that it is contrary to the observed phenomena to assume that the grading was done at one period and the débris accumulated during some other period.

WILLIS T. LEE.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE[1]

CLEMENTS, SMYTH, BAILEY, and VAN HISE[2] describe the Crystal Falls iron-bearing district of Michigan.

The rocks of the district comprise two groups, separated by unconformities. These are the Archean and the Algonkian. The Algonkian includes both the Lower Huronian and the Upper Huronian series, and these are also separated by unconformities. The terms Lower Huronian and Upper Huronian are applied to the series which occur in this district because they are believed to belong to the same geological province as the Huronian rocks of the north shore of Lake Huron, and to be equivalent to the Lower Huronian and Upper Huronian series which there occur.

The Archean is believed to be wholly an igneous group, and therefore no estimate of its thickness can be given. It covers a broad area in the eastern part of the district, and from this several arms project west. West of the main area there are two large oval areas of Archean.

The Lower Huronian series, from the base upward, comprises the Sturgeon quartzite, from 100 feet to more than 1000 feet thick; the Randville dolomite, from 500 to 1500 feet thick; the Mansfield slate, from 100 to 1900 feet thick; the Hemlock volcanic formation, from 1000 to 10,000 or more feet thick; and the Groveland formation, about 500 feet thick. A minimum thickness for the series is about 2200 feet, and a possible maximum thickness is more than 16,000 feet. However, in the latter case, a large part of the series is composed of volcanic material. It is not likely that the sediments at any one place are as much as 5000 feet thick.

The Upper Huronian is a great slate and schist series, which it is not possible to separate on the maps into individual formations. It is impossible to give even an approximate estimate of the thickness of this series.

[1] Continued from page 443, Vol. VIII, JOUR. GEOL.

[2] The Crystal Falls Iron-bearing District of Michigan, by J. MORGAN CLEMENTS and H. L. SMYTH, with a chapter on the Sturgeon River Tongue, by W. S. BAYLEY, and an Introduction by C. R. VAN HISE: Mon. U. S. Geol. Surv., No. XXXVI, 1899. With geological maps.

Various igneous rocks intrude in an intricate manner both are Upper Huronian and the Lower Huronian series.

In the following paragraphs the descriptions of the formations we summarized somewhat more in detail.

The Archean.— The Archean consists mainly of massive and schistose granites and of gneisses. Nowhere in the Archean have any rocks of sedimentary origin been discovered. The Archean has been cut by various igneous rocks, both basic and acid, at different epochs. These occur in the form both of bosses and of dikes, the latter sometimes cutting, but more ordinarily showing a parallelism to, the foliation of the schistose granites. The granites must have formed far below the surface, and therefore must have been deeply denuded before the transgression of the Lower Huronian sea. The Archean granites and gneisses and the earlier intrusives alike have been profoundly metamorphosed, and at various places have been completely recrystallized.

The Lower Huronian series.—The Sturgeon quartzite, the first deposit of the advancing sea, when formed consisted mainly of sandstone, but in places at the base it consisted of coarse conglomerate. The conglomerate is best seen in the Sturgeon River tongue. Elsewhere evidence of conglomeratic character at the base of the formation is seen, but the metamorphism has been so great as nearly to destroy the pebbles. However, in the Sturgeon River tongue is a great schistose conglomerate, which, while profoundly metamorphosed, still gives evidence of the derivation of its material from the older Archean rocks. The sandstone has been changed to a vitreous, largely recrystallized quartzite, which now shows only here and there vague evidence of its clastic character.

The Sturgeon formation varies from probably more than 1000 feet in thickness in the Sturgeon River tongue to less than 100 feet in thickness at places in the Felch Mountain range, and is altogether absent in the northeastern part of the district.

In the southeastern part of the district the Sturgeon quartzite is overlain by the Randville dolomite. In the central part of the district the quartzite between the Archean and the Randville is so thin that it cannot be represented on the maps as a separate formation. In the northeastern part of the district a quartzite, resting on the Archean, but occupying a higher position stratigraphically than the Randville dolomite, is overlain by an iron-bearing formation. It appears,

therefore, that the Sturgeon sea gradually overrode the district, and that at the time the Sturgeon quartzite was deposited in the southeastern part of the area the Archean was not yet submerged in the central and northeastern parts of the district. However, since the quartzite resting on the Archean in the latter area cannot be separated lithologically from the Sturgeon quartzite, both are given the same formation color, but the later quartzite is given a separate letter symbol. The quartzite color therefore represents the transgression deposit of the same general lithological character, rather than a formation all parts of which have exactly the same age. While nowhere in the district is there any marked discordance between the schistosity of the Archean and the Sturgeon quartzite, the conglomerates at the base of the latter formation in the Sturgeon River tongue are believed to indicate a great unconformity between the Archean and the Lower Huronian series. The change from the Sturgeon deposits to those of the Randville was a transition.

The Randville dolomite is a nonclastic sediment, and is believed to mark a period of subsidence and transgression of the sea to the northeast, resulting in deeper water for much of the district. Since the Randville dolomite has its full thickness on the Fence River just east of the western Archean oval, and does not appear at all about the Archean oval a short distance to the northeast, it is probable that the shore line, during Randville time, was between these two areas and that the land arose somewhat abruptly toward the northeast. As the Randville formation has a thickness of 1500 feet, it probably represents a considerable part of Lower Huronian time.

Following the deposition of the Randville dolomite, deposits of very different character occur in different parts of the district. These deposits are: (1) The Mansfield formation, (2) the Hemlock volcanic formation, and (3) the Groveland formation.

The Mansfield formation was a mudstone, which has subsequently been transformed into a slate or schist. The Hemlock formation is mainly a great volcanic mass, including both basic and acid rocks, lavas, and tuffs, but it contains also subordinate interbedded sedimentary rocks. This formation occupies a larger area than other of Lower Huronian formation, and is perhaps the most characteristic features of the Crystal Falls district. The Groveland is the iron-bearing formation. It includes sideritic rocks, cherts, jaspilites, iron ores, and other varieties characteristic of the iron-bearing formations

of the Lake Superior region. In all important respects these rocks are similar to those of the Negaunee formation of the Marquette district, with the exception that in the southeastern part of the Crystal Falls district, associated with the nonclastic material, there is a considerable proportion of clastic deposits. The Groveland formation contains iron carbonate and possibly glauconite, from which its other characteristic rocks were derived.

The variability in the character of the deposits overlying the Randville formation is probably caused by the great volcanic outbreaks in the western part of the district. In the southern and southeastern parts of the area the deposit overlying the Randville formation is the Mansfield slate and schist. North of Michigamme Mountain and of the Mansfield area the Mansfield formation is replaced along the strike by the Hemlock volcanic formation, which directly overlies the limestone for most of the way about the western Archean oval. The effect of the volcanic outbreak apparently did not reach so far as the northeastern part of the district.

Overlying the Mansfield formation in the southeastern part of the district and the Randville formation in the central part of the district is the Groveland iron-bearing formation. In the Mansfield slate area the iron-bearing rocks appear near the top of the Mansfield formation intercalated with the slates. The Groveland formation cannot be certainly traced farther north than the northeastern portion of the western Archean oval. It is apparently replaced along the strike by the Hemlock volcanics.

In the northeastern part of the district the Groveland formation, equivalent to the Negaunee formation of the Marquette district of Michigan, is found above the Ajibik formation. The occupation, in the western part of the district, by the Hemlock volcanics of the same part of the geological column as occupied by the Hemlock volcanics east of the western Archean oval, the Mansfield slate, and the Groveland formation, is explained by the fact that in the western part of the district the volcanoes broke out and there continued their activity longest. While north of Crystal Falls the volcanic rocks were laid down, the Mansfield formation was being deposited in the southeastern part of the district. This activity continued there through the time in which the Groveland formation was being deposited in other parts of the district.

From the foregoing it appears that the Hemlock formation in the western part of the district is equivalent:

1. East of the western Archean oval, to the Hemlock volcanics found there and the overlying Groveland formation.

2. At Michigamme Mountain, to the Mansfield slates and the Groveland formation.

3. In the Mansfield area, to the Mansfield slates and the Hemlock volcanics occurring there.

4. In the southeastern part of the district, to the Mansfield and Groveland formations.

The replacement of an iron-bearing formation by the great volcanic formation just described is exactly paralleled in the Upper Huronian rocks of the Penokee iron-bearing series, where the pure iron-bearing formation is replaced at the east end of the district by a great volume of volcanic rocks intercalated with slates and containing bunches of iron-formation material.

Following the deposition of the Lower Huronian series, the region was raised above the sea and eroded to different depths in different places. In the Felch Mountain range the only formations above the Randville dolomite are a thin bed of slate and the Groveland iron formation. In the northeastern part of the district only a thin belt of iron-formation rocks remains. In the central and western parts of the district there is a great thickness of volcanics. This, however, does not imply a difference of erosion equal to the difference in thickness of these rocks, for doubtless when the volcanics were built up there was contemporaneous subsidence, so that at the end of Lower Huronian time there may have been little variation in the elevation of the upper surface of the series, but very great differences in its thickness.

The Upper Huronian.— After the Lower Huronian series was deposited the district was raised above the sea, may have been greatly folded, and was eroded to different depths in different parts of the district.

Following the earth movements and erosion, the waters for some reason advanced over the district, and the Upper Huronian series was deposited. The basal horizon was a conglomerate, which has, however, very different characters in different parts of the district.

In the eastern half were Archean rocks, the Sturgeon quartzite, the Mansfield slate, and the Groveland iron formation. Upon these was deposited a sandstone which locally was very ferruginous. This has

subsequently been changed iuto a ferruginous quartzite. The typical occurrence of this quartzite is at the end of the Felch Mountain range. It also appears between the Archean ovals in the northeastern part of the district. If distinct conglomerates were formed at the bottom of this quartzite, they are buried under glacial deposits or have disappeared as the result of metamorphism.

In the western part of the district the rocks of the Lower Huronian at the surface are the great Hemlock formation, and here the basal horizon of the Upper Huronian is a slate or slaty conglomerate, the fragments of which are derived mainly from the underlying Hemlock formation. The sandstones and conglomerates varied upward into shales and grits, which have been subsequently altered into mica-slates and mica schists. After a considerable thickness of mudstone and grit was deposited, there followed a layer of combined clastic and non-clastic sediments, the latter-including iron-bearing carbonates. These appear to be at a somewhat persistent horizon, and in this belt are found the iron-formation rocks, and iron ores in the Upper Huronian in the vicinity of Crystal Falls. Above these ferruginous rocks there was deposited a great thickness of shales and grits which have been transformed into mica-slates and mica-schists.

Since the deposition of the Upper Huronian the rocks of the district have been folded. The more complex folds vary from a north-south to an east-west direction. The closer folds in the northeastern part of the area are nearly north-south. In the central part of the area the closer folds strike northwest-southeast. In the eastern and southeastern parts of the district the closer folds are nearly east-west. All of these folds have steep pitches.

Subsequent to, or during the late stage of, this time of folding there was a period of great igneous activity, probably contemporaneous with the Keweenawan. At this time there were introduced into both the Lower and Upper Huronian vast bosses and numerous dikes. The intrusives vary from those of an ultrabasic character, such as peridotites, through those of a basic character, such as gabbros and dolorites, to those of an acid character, such as granites. These intrusives, while altered metasomatically, do not show marked evidence of dynamic metamorphism; therefore the conclusion that they were introduced later than the period of intense folding already described.

Cambrian rocks overlie unconformably the rocks above described.

DESCENDING SUCCESSION OF FORMATIONS IN THE MARQUETTE, CRYSTAL FALLS, AND MENOMINEE DISTRICTS.

MARQUETTE DISTRICT	CRYSTAL FALLS DISTRICT	MENOMINEE DISTRICT
UPPER MARQUETTE	UPPER HURONIAN	UPPER MENOMINEE
1. Michigamme formation, bearing a short distance above its base an iron-bearing horizon, and being replaced in much of the district by the Clarksburg volcanic formation.	1. Michigamme formation, bearing a short distance above its base an iron-bearing horizon.	1. Great Slate formation.
2. Ishpeming formation, being composed of the Goodrich quartzite in the eastern part of the district, and of the Goodrich quartzite and the Bijiki schists in the western part of the district.	2. Quartzite in eastern part of the district.	
Unconformity	Unconformity	Unconformity
LOWER MARQUETTE	LOWER HURONIAN	LOWER MENOMINEE
1. Negaunee iron formation, 1000 to 1500 feet.	1. The Groveland formation, about 500 feet thick.	1. Vulcan iron formation containing slates.
2. Siamo slate, in places including interstratified amygdaloids, 200 to 625 feet thick.	2. Hemlock volcanic formation, 1000 to 10,000 feet thick. In western part of district also occupies place of (1) and (3).	2. Antoine dolomite.
3. Ajibik quartzite, 700 to 900 feet.	3. Mansfield formation, 100 to 1900 feet thick.	
4. Wewe slate, 550 to 1050 feet.		
5. Kona dolomite, 550 to 1375 feet.	4. Randville dolomite, 500 to 1500 feet thick.	
6. Mesnard quartzite, 100 to 670 feet.	5. Sturgeon quartzite, 100 to 1000 feet thick.	3. Sturgeon quartzite.
Unconformity	Unconformity	Unconformity
ARCHEAN	ARCHEAN	ARCHEAN

Lane[1] gives a detailed account of the geology and petrography of Isle Royale, Lake Superior. The island trends north of east and the edges of the strata outcrop in approximately this direction. The rocks are interbedded conglomerates, sandstones, and traps of Keweenawan age, dipping in a southerly direction at angles varying from 8–32°, the higher dips in general to the north. Faults are shown to exist at various places with directions approximately northeast–southwest and northwest–southeast, and the probable existence of other more extensive faults running entirely across the island is indicated. The detailed sections with correlations with the Keweenawan of other parts of Lake Superior are given in table on page 520.

Hubbard[2] discusses the geology of Keweenaw Point with particular reference to the felsites and their associated rocks. The term felsite is used to include all the very fine-grained and highly acid igneous rocks. These occur at a number of horizons below the Bohemian conglomerate, so-called from the fact that it skirts the northern side of this range near the northeastern end of Keweenaw Point. The outcrops of felsite studied occur in Sec. 30, T. 58, R. 27 (New England or Keystone location); Sec. 25 (?), Sec. 35 (Fish Cove), Secs. 26 and 27 (Little Montreal River), all in T. 58, R. 28; Secs. 29 and 30, T. 58, R. 28 (Bare Hill and westward therefrom) Secs. 23 and 24, T. 58, R 29 (Mt. Houghton) and both eastward and westward therefrom; Sec. 10, T. 57, R. 31 (Suffolk location, Praysville); Sec. 4, T. 56, R. 32 (Allouez Gap, east of the Kearsage and Wolverine mines); Sec. 30, T. 56, R. 32 (falls on branch of Trap Rock River); Sec. 36, T. 56, R. 33 (Douglass Houghton Falls), and Sec. 1, T. 55, R. 33 (Hecla and Torch Lake R. R).

The evidence concerning the source of the Keweenawan lavas is considered and it is concluded that they may probably have come from a higher level somewhat back from the edges of the present Keweenawan basin.

With this probability in mind, the following hypotheses are suggested:

1. The irregularities in the lower beds of the Keweenaw series in the Portage Lake area, contrasted with the greater regularity of the

[1] Geological Report on Isle Royale, Michigan, by A. C. LANE: Geol. Surv. of Mich., Vol. VI, 1898, Pt. 1, pp. 1–281. With geological map.

[2] Keweenaw Point with Particular Reference to the Felsites and their Associated Rocks, by L. L. HUBBARD: Geol. Surv. of Michigan, Vol. VI, 1893–1897, Pt. 2, pp. 184. With plates.

Name		Depth in drill hole, feet	Total thickness from o feet	Number in Eagle River section	Thickness in Eagle River Section	Copper Falls section	Tamarack section	Conglomerate numbers	Distances	Minnesota correlations
Upper sandstone and conglomerate		....	2600	2500	....	....	....	....	....	....
First known trap	Marvine's (c)	0	0	No. 1	....	....	....	....	....	
Ophites, numerous sandstones		....	....	....	....	....	....	....	....	
Island mine conglomerates		....	....	....	....	....	....	....	....	
Transition flows, porphyrite and ophite		170 193	567 589	35	1146	1035 1012	2146	18 ?	....	
Scoriaceous conglomerate	Marvine's (b)	415 426	806 817	44	1417	745	2021	17	....	
Green porphyrites		279	1100	63	1810	368	1639	17	853	Temperance River group ?
Scoriaceous conglomerate "Ashbed"		291	1112	65	....	....	....		885	
Porphyrites	Marvine's (c)	....	....	....	2035	160	....	....	....	
Red sandstone		....	....	....	....	0	....	....	....	
Porphyrites, etc		377 419	1526 1567	80 ?	2432 2496	495 500	1081 1053	16	1435 1445	
Felsite tuff		81 91	2035 2045	....	....	....	160	*	....	
Ophite, and the thickest ophite—the Greenstone Conglomerates—the Allouez or "Slide"		....	....	90	2840	Central	....	....	....	Beaver Bay group ?
		....	....	108	4120	mine	....	....	....	
Amygdaloids mainly and thin ophites		363 386	2310 2332	....	....	0	0	15	2345 2378	
		136 175	2570 ?	....	....	660	....	14	....	Agate River group ?
		133	3197	....	....	1474	1309	13	....	
		....	....	....	....	....	....	12	....	
Minong	breccia	386	4030						4853	
	porphyrite	426	4068	"Kingston" or		2599	2239	11		
	trap	456	4097	Kearsarge ?					4873	
Various beds ending with a thick ophite		536	4174							
Huginnin porphyrite		....	....	....	....	....	....	....	....	
Ophites		367 436	5194 5260							
Felsitic conglomerate		475 487	5868 5879					6	7643	
Various igneous flows and conglomerates		....	....	....	....	....	....	....	....	
Felsitic conglomerate and felsite tuff		786 910	6155 6267							
Felsite		....	6400	Prays ville		....	....	....	....	

* 67.7 above Allouez at Peninsula mine.

higher part of the series, suggest that in this area, near the contact between the Keweenaw series and the Eastern sandstone, we are on the edge of an early-Keweenawan or pre-Keweenawan basin.

2. If the lower beds of the Keweenaw series near Portage Lake rested on the sides of a basin, the later beds of the series from here eastward lay at a higher altitude and, excepting those of the South Trap Range, were eroded in pre-Potsdam time together, possibly, with a part of the underlying Archean.

3. The porphyries found on Keweenaw Point at the contact between the Keweenaw series and the Potsdam sandstone may be in part either,

a. Marginal facies of the underlying Archean;

b. Intrusive in the early Keweenawan;

c. Early interbedded flows of the Keweenaw series; or,

d. Remnants of late Keweenawan intrusions by which the eastern margin of the series was broken up and its degradation hastened.

Seaman[1] gives a summary of the geological history of the Keweenawan copper range in Michigan, Wisconsin, and Minnesota. No new point on the geology of the region is added to those already recorded.

Hall[2] describes the pre-Cambrian crystalline rocks of the Minnesota river valley of southwestern Minnesota. These rocks appear in numerous exposures along the river, protruding from the drift, from southeast of New Ulm to Ortonville on the northwest. The great bulk of the crystalline rocks are granites and gneisses. These appear for the most part in the river bottoms, but stand also in a few isolated knobs on the higher ground south and west of the river. There are many varieties of granites and gneisses and all gradations between them. They are taken as a whole to represent the Archean or Basement complex.

Associated with the granites and gneisses are a much smaller number of exposures of gabbros and gabbro-schists. These present many varieties, all of which are believed to have resulted from the alteration of two original forms and their intergradations—a hypersthene-bearing gabbro and a hypersthene-free gabbro.

[1] Geology of the Mineral Range, by A. E. SEAMAN: First Ann. Rept. of the Copper Mining Industry of Lake Superior, 1899, pp. 49–60.

[2] The Gneisses, Gabbro-Schists and Associated Rocks of Southwestern Minnesota, by C. W. HALL: Bull. U. S. Geol. Surv., No. 157, 1899, pp. 131. With geological maps.

Peridotite is found in one exposure only in this valley, three miles southeast of Morton. The relations to the other rocks of the area could not be determined. Cutting the gneisses and gabbro-schists throughout the area are numerous dikes of diabase. They vary in width from a fraction of an inch to 175 feet. Their age is probably Keweenawan.

Southeast of Redstone and near New Ulm are exposures of quartzite associated with coarse quartzite conglomerate. Near Redstone the strike of the quartzites is N. 60–70° W., and their dip varies from 5–27° N. In New Ulm the strike is N. 15° E., and the dip varies from 10–15° S. E. The quartzite is believed to be the same as the quartzite found in a deep well at Minneopa Falls, near Mankato, Minn., which is covered by a quartzite conglomerate of Middle Cambrian age. The quartzite of Redstone and New Ulm is above the Archean granite and gneiss. It is believed to be of Huronian age, but whether Upper or Lower is unknown.

Overlying the crystalline rocks are Cretaceous shales and sandstones, which appear in rare exposures in the valley, and glacial drift.

Coleman[1] discusses areas mapped by Logan as Huronian north of Lake Huron and the east end of Lake Superior. The two contacts described by Irving and Van Hise as contacts of the Lower Huronian and Laurentian rocks were examined. At the first, on the islands four miles east of Thessalon, jasper and chert fragments were found in the conglomerate above the Laurentian, indicating that the conglomerate is probably a part of an upper series, younger than a series of rocks, not Laurentian, from which the jasper must have been derived. At the other contact, on the road between Sault Ste. Marie and Garden River, it is concluded that the conglomerate is possibly a crushed conglomerate formed by faulting instead of a water-formed rock.

Certain green and gray schists inclosed in the Laurentian gneisses are believed to represent the western Keewatin of Lawson.

The Laurentian and Huronian contact at Goulais and Batchawana bays was found to be in general of the nature of an eruptive contact, although a clear example of the inclusion of a typical Huronian rock in the Laurentian was not observed.

The slate-conglomerate of Doré River contains no bowlders that are distictly Laurentian. It contains only fragments of schists and

[1] Copper Regions of the Upper Lakes, by A. P. COLEMAN: Rept. of the Bureau of Mines, Ontario, Vol. VIII, Pt. 2, 1899, pp. 121–174.

eruptives from rocks which have been called Huronian. It probably has closer affinities to Lawson's Keewatin than to Logan's Original Huronian.

On the shores of Heron Bay the schist-conglomerate and slate were examined. The conglomerate contains fragments mainly of granite. These rocks are more closely allied to the Keewatin than to the Original Huronian type.

In general it is believed that Logan mapped as Huronian, rocks which are really Huronian and Keewatin.

The ascending succession for the region as indicated by the above facts is as follows: Keewatin, consisting mainly of basic green-schists; Laurentian, consisting mainly of moderately acid eruptives; and Huronian. The term Laurentian is confined to areas of granite and granitoid gneiss corresponding to the Ottawa Gneiss of eastern Canada, and having eruptive relations to the Keewatin.

The Keweenawan rocks of the various area on the north shore of Lake Superior were studied, but no important conclusions were reached differing from those of Irving. One variety of conglomerate, made up chiefly of underlying Laurentian rocks is common on the north shore, which apparently has not been found on the south shore.

Comments.—This discussion points toward the conclusion that the Original Huronian rocks of Logan are largely a series above and later than certain rocks to the west mapped by Logan as Huronian, and other rocks still farther to the west mapped by Lawson as Keewatin; further that the Laurentian rocks intrude the earlier series, and are unconformably overlain by the later Original Huronian series of Logan.

That the Original Huronian, in large part, is younger than some of the Keewatin rocks of Lawson is possible. The finding of chert and jasper fragments in the conglomerate cited by Irving and Van Hise as Lower Huronian would show that more of the series belongs to an upper division than was supposed.

However, as Dr. Coleman himself would fully agree, there still remains evidence to indicate that rocks of both Upper and Lower Huronian series are present in the Original Huronian area, and for the Keewatin of Lawson the evidence is conclusive that two or more series are represented. In view of this wide range of rocks in both areas, and the wide separation of the areas it is unsafe at present to make a definite statement concerning the relative ages of Lawson's Keewatin

and Logan's Original Huronian, based on lithological character and relations to the intrusives.

Dr. Coleman's conception of the Laurentian is the same as that attributed to the Canadian geologists in general in the comments on p. 440.

McInnes[1] describes the geology of the Seine River and Lake Shebandowan map-sheets, which cover an area extending west and northwest of Port Arthur, Ontario. Laurentian granites and gneisses with many variations occupy three fourths of the area. The relations to the overlying Keewatin and Coutchiching rocks, wherever they have been found in contact, have been those of intrusion.

The Huronian is represented by Coutchiching and Keewatin rocks.

Coutchiching mica-schists and fine-grained gneisses, a continuation of Lawson's Coutchiching in the Rainy River district to the west, enter the area of the Seine River sheet on the west side. However, toward the east these rocks become associated with large quantities of gneisses, and for the eastern two thirds of the Seine River sheet and for the entire Lake Shebandowan sheet the gneisses are predominant and the belt is mapped as Laurentian. In other parts of the district the Keewatin schists, near their contact with the Laurentian gneisses, assume a character exactly similar to the Coutchiching schists and associated gneisses, and could not be lithologically distinguished. Indeed, the Coutchiching seems to be an extremely altered phase of the Keewatin.

In long bands infolded with the Laurentian and conforming in strike with the foliation of the gneiss are bands of Keewatin rocks varying greatly in width. They vary in composition from extremely basic igneous masses, and their derived products, to acid quartz-porphyries, and their derived products, and include also quartzites, conglomerates, and slates. The basic rocks form the largest volume of the rocks of the series. The series is separated lithologically in mapping into three divisions. There can be no doubt that the Keewatin here includes rocks which are of widely differing age.

Overlying unconformably the Keewatin rocks is the Steep Rock Lake series, so named from its occurrence in the neighborhood of this lake. The series is mapped as an upper division of the Keewatin series. As

[1] "The Geology of the Area Covered by the Seine River and Lake Shebandowan Map-Sheets, comprising Portions of Rainy River and Thunder Bay Districts, Ontario," by WM. MCINNES: Ann. Rept. Geol. Surv. of Canada, Vol. X, Pt. H, 1899, pp. 13–51. With geological map.

described by Smyth it comprises conglomerate, limestone, clay-slate, and various basic volcanic and intrusive rocks. Because of the folding of the series it is believed to be older than the Animikie strata of Thunder bay.

Animikie rocks occur in a small area in the southeast corner of the Shebandowan sheet. They overlie unconformably the Keewatin and Laurentian rocks, and from their stratigraphical relations to the overlying formation farther east on Lake Superior they are believed to be of Lower Cambridge age.

Comments.—The mapping of this area of these sheets has been largely lithological, the red granites and gneisses and their associated rocks of various ages being mapped as Laurentian, and the green rocks and the associated sedimentaries being mapped as Huronian. However, a distinct advance is made in seeing that some of the Coutchiching rocks are no more than metamorphosed Huronian or Keewatin rocks. This is a frank awowal that the Coutchiching series is a lithological, not a structural unit.

The Steep Rock Lake conglomerate was considered by Smyth and Pumpelly as the basal portion of the Lower Huronian, and the underlying rocks as Archean. McInnes has mapped the underlying rocks as Keewatin, and has included in them sedimentary and igneous rocks. He has not separated from them sedimentary rocks which may be the equivalent of the Steep Rock series.

C. K. Leith.

STUDIES FOR STUDENTS

RESULTS OF TESTS OF WISCONSIN BUILDING STONE III[1]

IN this the concluding paper on the testing of building stones I will summarize and discuss various tests which I made in the laboratory of the Wisconsin Geological Survey during the winter of 1897–8.

In examining the tests recorded in some of the reports on building stones I found them to be really of little value, either on account of the failure of the operator to describe carefully the methods employed in making the tests or owing to insufficient care in manipulation and computation. It has been noted that among sedimentary rocks the results of tests on samples from different parts of the same quarry may be very different. Such differences may be even more marked than those that occur between samples from different quarries within the same area. It is possible to select samples from a quarry which will give very high tests, while a greater part of the stone may be of the poorest kind. Valuable results can only be obtained when tests are made upon samples which are a fair average of the stone as it occurs in the quarry.

For making the tests herein discussed, the author endeavored to obtain samples which represented as nearly as possible average No. 1 stone. The tests were performed as nearly as possible in accordance with the instructions laid down in the previous paper. The utmost care was exercised in obtaining truthful results, and it is believed that the figures given are nearly accurate for the samples tested.

[1] The illustrations accompanying this paper are used by permission of the director of the Wisconsin Geological and Natural History Survey. A fuller discussion of these tests will be found in Bulletin No. IV of the Wisconsin Geological and Natural History Survey reports.

CRUSHING STRENGTH

The individual test which is employed perhaps more than any other to determine the strength and durability of a stone is the crushing strength test. For years certain architects and builders have relied upon this test almost exclusively for forming an estimate of the suitability of a stone for all kinds of public and private buildings. This general use of the crushing strength test is still prevalent in some sections of the country.

In order to be assured of the reliability of the machine in which the crushing strength tests were to be made, comparisons were made with tests made in two other machines on samples from the same quarries. One of the machines used was also calibrated to give positive assurance of its reliability. In making the tests, note was taken of the position of the sample in the machine with respect to bedding or schistosity.

Twenty-seven samples of granite from twelve different quarries were tested. The lowest crushing strength obtained was 12,704 pounds per square inch, while the highest was 47,674 pounds per square inch. The average crushing strength of all the samples tested was 27,023.7 pounds per square inch. The minimum crushing strength was above the maximum crushing strength obtained for sandstone, and was obtained on a sample of granite gneiss in which the lamination was diagonal to the direction of the pressure. As far as my knowledge extends the maximum crushing strength is the highest yet recorded for any rock tested in the United States. It was obtained from a sample of rhyolite on which the pressure was applied normal to the head or in the direction of the rift.

It has been generally supposed that the crushing strength of a stone is least in the direction of the rift or lamination, but apparently this is not true in the case of the rhyolite in question. This rhyolite consists of elongated crystals of feldspar and other minerals in a very dense groundmass, forming what one might consider a very compact bundle of fibers. A rock with such a structure can apparently sustain a greater pressure when applied in the direction of these fibers than when applied across them.

Further, a careful examination of the polished faces of this rock shows that the feldspar crystals are broken by numerous cross fractures. These small, scarcely perceptible fractures may account in part for the less load which the rock is capable of sustaining normal to the rift. The cone which remained after crushing this sample of rhyolite is shown in Plate I.

The highest crushing strength obtained for true granite was 43,973 pounds per square inch, which was obtained on a sample of the Montello stone. This, so far as my knowledge goes, is the highest crushing strength that has been recorded for any United States granite. It exceeds the highest test on the Fourche Mountain granite[1] of Arkansas by nearly 15,000 pounds per square inch, while the highest test on the granite from St. Cloud,[2] Minn., is 16,000 pounds less than this. The granite from Redgranite, Waushara county, also gave a crushing strength of over 36,000 pounds per square inch, which exceeds the highest test made on the Fourche Mountain granite by 7000 pounds per square inch. These illustrations give evidence that in at least three different areas in Wisconsin granite and rhyolite occur, which, as far as known, surpass in strength granite or rhyolite from any other quarry in the United States.

Most of the granite samples broke with an explosion. Ordinarily an upper pyramid or cone, such as shown in the accompanying illustration, Plate I, was all that remained after the test. In a few cases a lower or opposite pyramid remained, but as a rule this part of the sample was reduced to powder. In many of the cones that remained a concentric structure had been developed through the pressure, which had much the appearance of cleavage. This is nicely shown in the accompanying illustration, Plate II.

Thirty-one tests were made on limestone from eleven different quarries. The strongest sample tested gave a crushing strength of 42,787 pounds per square inch, which is about 18,000 pounds higher than any known test recorded for limestone,

[1] Annual Report Arkansas Geological Survey, 1890, Vol. II, p. 42.

[2] Geological and Natural History Survey of Minnesota, 1884, Vol. I, p. 196.

dolomite, or marble in the United States. The stone which gave this test was a thoroughly crystalline, well compacted, and homogenous dolomite. The weakest sample tested gave a crushing strength of a little over 6600 pounds per square inch. The strength of the weakest limestone is very little less than that of the ordinary sandstones tested. The sample which gave the highest test was from the Marblehead Lime and Stone Company's quarry in the Niagara formation. Other samples from the Niagara formation gave tests of 39,983 pounds, 36,731 pounds, 33,485 pounds, 32,171 pounds, and 31,800 pounds per square inch.

The crushing of the samples of limestone was ordinarily accompanied with less noise than the granite. Occasionally the samples scaled off along the edges and corners before the maximum load was applied. In some cases two pyramids were developed, but as a rule, only one remained after crushing the more perfectly prepared cubes. The pyramids resulting from the crushing of limestone are ordinarily much steeper and more slender than those of the granite. Occasionally wedge-like forms were developed which resembled the wedge-shaped pyramids of the granite, as shown in Plate II, Fig. 2 and Plate IV, Fig. 3. Occasionally the samples are reduced to splinters, even the pyramids falling in pieces when raised from the steel plate. The cone which remained after the "record sample" of limestone was crushed is shown in Plate III, Fig. 6. Other typical pyramids resulting from crushing limestone samples are shown in Plate III, Figs. 1–5.

The crushing strength was determined for forty-five samples of sandstone from eleven different quarries. The samples from several of the quarries were thoroughly indurated while others were very soft and incoherent. In most cases the cementing material was silica but in some of the weaker samples iron oxide was the principal bonding constituent. Compared with the strength of the granite and limestone, the sandstone may be considered relatively weak. The sample which gave the highest strength test was from the quarry of the Chicago and

Northwestern Railway Company at Ablemans. This sample gave a test of 13,431 pounds per square inch. The lowest test was 1658 pounds per square inch, made on a sample of Lake Superior brown sandstone tested on edge. The lowest test across the bed was 2502 pounds made on a sample of Dunnville sandstone. The average strength of all the sandstone samples tested, one half of which were on edge and the other half on the bed, was 6361 pounds per square inch. The average crushing strength of twenty tests of the Lake Superior brown sandstone, one half of which were on edge and the other half on the bed, was 4618 pounds per square inch. This is a somewhat higher average crushing strength than that recorded for the Bedford öolitic limestone of Indiana.[1]

The weaker the sandstone and the more uniform the grains, the more perfect are the pyramids which develop. In the stronger samples the pyramidal form is replaced by the conical. In the samples of moderate strength almost perfect pyramids form on both the upper and lower sides, as shown in the accompanying illustration, Plate IV, Figs. 1 and 4.

In performing these tests my attention was called to the fact that the crushing strength on edge of the weakest samples was considerably less than that on the bed, while in the stronger rocks the difference was much less. The compressive strength of several different limestones was higher when the pressure was applied along the bed than when applied across it. The Berlin rhyolite, which is the strongest stone tested, gave the highest strength test when the pressure was applied in the direction of easiest parting. These results indicate that there are exceptions to the general rule that a stone will withstand the greatest pressure when applied normal to the bed. Apparently the rule applies only to stone which has a low compressive strength. When the compressive strength is very high the opposite result is fully as likely to occur and may even prove the rule.

The manner in which the cubes of stone break indicates to a greater or less extent the strength of the stone. Crushing a

[1] Twenty-first Annual Report of the Indiana Department of Geology and Natural Resources, p. 317.

stone which has a compressive strength of less than 10,000 pounds per square inch usually results in the formation of two quite well defined pyramids. The pyramids resulting from crushing a stone with a compressive strength of between 10,000 and 20,000 pounds per square inch are ordinarily less perfect. The pyramids resulting from testing stone of this class are frequently wedge-shaped but more often they are intermediate between a pyramid and a cone. The crushing of cubes having a compressive strength of over 30,000 pounds per square inch usually results in the formation of only one pyramid which has more of a conical than pyramidal outline.

In crushing the granite and also some of the limestone and sandstone cubes a concentric structure was developed similar to that illustrated in Plate II, Figs. 4, 5, and 6.

TABLE I.

CRUSHING STRENGTH[1]

Ultimate Strength in Pounds per Square Inch.

	Highest test	Lowest test	Average
Granite and rhyolite: twenty-seven samples from twelve different quarries	47,674	12,704	27,023.7
Limestone: thirty-one samples from eleven different quarries	42,787	6,675	25,312.8
Sandstone: forty-five samples from eleven different quarries	13,699	1,658	6,125.0

TRANSVERSE STRENGTH

The determination of the modulus of rupture is of as great if not greater importance than the crushing strength. As previously indicated, it is especially valuable in determining the required thickness of a stone which is intended to be supported at the ends, and which carries a heavy weight of superstructure in the middle.

The modulus of rupture was determined for only two Wisconsin granites. The results in each case were over 2300 pounds

[1] For detailed results of individual tests see Bulletin No. IV, Wisconsin Geological and Natural History Survey, "Building and Ornamental Stones," 1898.

per square inch. The average transverse strength of the Montello granite was over 3780 pounds per square inch. The samples broke suddenly, and the fracture extended diagonally across the center of the pieces.

The modulus of rupture was determined for samples of limestone from eight different quarries. The results ranged from 1164.3 pounds to 4659.2 pounds per square inch. The highest result obtained was on a sample of stone from the Laurea Stone Company's quarry at Sturgeon Bay. The stone from the Marblehead Lime and Stone Company's quarry at Eden gave a modulus of rupture of 3632 pounds per square inch. All of the transverse strength tests were high. The samples broke very close to the center and much quieter than the granite.

The modulus of rupture was determined for sandstone from six different quarries. The results ranged from 362.9 pounds to 1324 pounds per square inch. The highest test obtained was on samples from the Chicago & Northwestern Railway Company's quarry at Ablemans. Eight tests of the brown sandstone from the Lake Superior region gave an average modulus of rupture of about 500 pounds per square inch.

A comparative examination of the results shows that the finely crystalline limestone possesses a higher modulus of rupture than either the sandstone or granite. However, it is ordinarily less rigid than either of these stones, and is more liable to sag when suspended at the ends.

TABLE II

TRANSVERSE STRENGTH

Modulus of Rupture in Pounds per Square Inch

	Highest test	Lowest test	Average
Granite and rhyolite: four samples from two different quarries	3,909.7	2,324.3	3,156.2
Limestone: ten samples from eight different quarries	4,659.2	1,164.3	2,761.15
Sandstone: sixteen samples from six different quarries	1,324	150.2	558.8

MODULUS OF ELASTICITY

Up to the present time very few determinations of the modulus of elasticity have been made, especially in the United States. However, a knowledge of the modulus of elasticity is of value to architects and builders in many of their calculations.

The modulus of elasticity was determined for granite from eleven different quarries. The results varied between wide limits, ranging all the way from 156,000 pounds to 2,070,000 pounds per square inch. The first result is comparatively low, while the latter is very high. Four samples of granite from Wausau gave tests of from 1,040,000 to 1,815,000 pounds per square inch. The Athelstane granite from Amberg tested very close to 1,000,000 pounds per square inch. The Pike River gray granite from the same place tested nearly 1,500,000 pounds per square inch.

The modulus of elasticity was determined for limestone from four different quarries. The results obtained varied from 31,500 pounds per square inch to 869,400 pounds per square inch. The highest result was obtained for limestone from the Washington Stone Company's quarry which is located at Sturgeon Bay.

The modulus of elasticity was determined for samples of sandstone from ten different quarries. The results of these tests varied from 32,000 pounds to 400,800 pounds per square inch. The highest result was obtained for samples of white sandstone from the Chicago & Northwestern Railway Company's quarry at Ablemans. The modulus of elasticity of the Lake Superior brown sandstone ranged from 56,000 to 387,900 pounds per square inch.

In general it will be noted that the modulus of elasticity corresponds approximately with the crushing and transverse strength of the different rocks tested. The crushing strength, transverse strength, and modulus of elasticity were all lower for the sandstone samples tested than for either the limestone or granite.

TABLE III

MODULUS OF ELASTICITY

In Pounds per Square Inch

	Highest test	Lowest test	Average
Granite and rhyolite: twenty-one samples from eleven different quarries	2,070,000	156,000	1,068,634
Limestone: eleven samples from five different quarries	1,835,700	31,500	786,145
Sandstone: twenty-eight samples from ten different quarries	400,800	32,000	163,861

HARDNESS

The hardness of a stone can be easily determined with the abrading machine known as the Deval.[1] For making this test a definite quantity (5 kg) of cubical pieces of stone from two to two and one half inches in diameter are placed in one of the cylinders of this machine, which is then rotated for five hours at a rate of about thirty-three revolutions per minute. The percentage of dust which is worn off by this treatment is the measure of the hardness of the stone. The coefficient of wear, which is another and the usual method of expressing the hardness, is computed from the following formula:

$$Q = \frac{20 \times 20}{W},$$

in which

Q = the coefficient of wear

W = the quantity of dust formed.

Two samples of granite from each of two quarries were tested in the abrading machine, with the results given in Table IV. Quartzite from one quarry, trap rock from one quarry, and limestone from seven quarries were also tested, with the results given in Table IV.

TABLE IV

HARDNESS OR COEFFICIENT OF WEAR

	Highest	Lowest	Average
Granite: four samples from two quarries	4.88	3.54	4.14
Trap: two samples from one quarry	3.03	2.07	2.55
Quartzite: two samples from one quarry	2.70	2.28	2.49
Limestone: fourteen samples from seven quarries	2.22	0.79	1.51

[1] For description of this machine see the Report of the Massachusetts Highway Commission for 1899, pp. 59, 60.

SPECIFIC GRAVITY

The weight of a rock per cubic foot will increase with the specific gravity proper and decrease with the percentage of pore space. As indicated in a previous paper, the average specific gravity of the mineral constituents is taken as the specific gravity proper of the rock. Following this conception the pore spaces are not considered a part of the rock mass.

Twenty-five determinations of specific gravity were made on samples of granite from fourteen different quarries. The maximum specific gravity obtained was 2.713 and the minimum 2.629, while the average of all determinations was 2.655. Tests on twenty-two samples of limestone from eleven different quarries gave an average specific gravity of 2.806. The maximum specific gravity was 2.856 and the minimum 2.700. Tests on thirty-two samples of sandstone from sixteen different quarries gave an average specific gravity of 2.618. The maximum specific gravity was 2.660 and the minimum 2.524.[1]

In the case of the sandstone it is to be observed that the iron oxide which constitutes a part of the cement of the brown sandstone is not present in sufficient quantity to appreciably affect the specific gravity. The specific gravity of the granite, however, is influenced appreciably by the abundance of the ferro-magnesium minerals, as exemplified in the case of the Athelstane granite from Amberg, which gave the highest specific gravity test. An admixture of quartzose material naturally lowers the specific gravity of limestone.

The stone which gave the highest specific gravity was a very compact and finely crystalline dolomite, and it is interesting to note that samples from this same quarry gave the highest crushing and transverse strength of any of the limestone or dolomite tested.

WEIGHT PER CUBIC FOOT

Determinations of the weight per cubic foot were made for twenty-five samples of granite from fourteen different quarries.

[1] It is thought that this low specific gravity is due to an unknown error in manipulation.

The average weight per cubic foot according to these determinations was 163.29 pounds. All of the granites tested weighed within five pounds per cubic foot of one another.

The average weight of twenty-two limestone samples from eleven different quarries was 166.70 pounds per cubic foot. The maximum weight was 176.69 pounds per cubic foot and the minimum 148.50 pounds per cubic foot. The average weight of thirty-two samples of sandstone from sixteen different quarries was 136.36 pounds per cubic foot. The maximum weight was 153.63 pounds per cubic foot and the minimum 115.55 pounds per cubic foot.

POROSITY AND RATIO OF ABSORPTION

As has been previously pointed out, the porosity gives the volume relation between the pores and the mass of the stone, while the ratio of absorption gives the weight relation. None of the granites tested had a porosity of more than 1 per cent., while the porosity of most of the samples was about .45 of 1 per cent. Owing to the interlocking character of the grains, the pores of a granite are much smaller than those of arenaceous limestone or sandstone. The water is therefore taken up and given off very slowly. The ratio of absorption of the granite samples tested was nearly the same as the porosity.

The limestone samples gave porosities ranging from 13.36 per cent. to .14 of 1 per cent. The sample having a porosity of 13.36 per cent. had a ratio of absorption of about 5.6 per cent. The samples from the Marblehead Lime and Stone Company's quarry, which gave the high crushing and transverse strength tests, had a porosity of about .70 of 1 per cent.

The porosity of the sandstone samples ranged from 4.81 per cent. to 28.28 per cent. The average porosity of the brown sandstone samples was between 19 and 20 per cent. In the case of the samples of sandstone having a porosity of 28.28 per cent. the ratio of absorption was 15.22 per cent. The Lake Superior brown sandstones gave an average ratio of absorption of less than 10 per cent.

The walls of a building constructed out of a porous stone are seldom completely saturated with water, although they may be wetted by the water of imbibition which adheres as a film to the individual grains and is thus conducted through the body of the wall. If a stone with pores of capillary size should be saturated in any part with water and the supply be discontinued the interstatial water would be very quickly drawn off at the surface or at the base of the wall through capillarity. It rarely happens that atmospheric conditions are such that a stone with capillary pores can become saturated with water and freeze before the water is sufficiently dissipated to prevent injury.

Rocks in which the grains are closely compacted, without respect to size, will have a small percentage of pore space and also pores of very small size. Many of the pore spaces of the granite and limestone are certainly of not greater than sub-capillary size. Water is taken up and given off by a rock having pores of this size much more slowly than by one in which the pores are of capillary dimensions. When the sub-capillary pores of a rock contain water in any quantity they should be theoretically filled. The sub-capillary pores near the exposed surface of a stone wall may be filled by long-continued rains, although the water may never penetrate to any considerable depth. If such a period of weather is followed by freezing conditions a stone in which the pores are of sub-capillary size will be in greater danger than one having pores of capillary size. It should be remembered that stone is damaged by freezing only when the pores are over nine tenths filled with water.

A wall built out of granite or other stone in which the porosity may be very low, but the pores of sub-capillary size, is in as great danger from alternate freezing and thawing as a wall built out of sandstone or other rock in which the porosity is 15 or 18 per cent., but in which the pores are of capillary size. It must be understood that this does not apply to laminated, bedded, or shaly stone, between the layers of which the water may collect more rapidly than it can be carried off through the pores. Water which is thus collected along bedding or other parting

planes cannot be considered under the head of interstatial water, although it is a very prominent cause for the disintegration of building stone.

TABLE V

	Specific gravity	Porosity	Ratio of absorption	Weight per cubic foot
Granite:				
Maximum	2.713	.55	.500	169.05
Minimum	2.629	.019	.04	163.29
Average	2.655	.329	.158	164.98
Limestone:				
Maximum	2.856	13.36	5.60	176.69
Minimum	2.700	.53	.19	148.50
Average	2.806	4.89	1.946	166.70
Sandstone:				
Maximum	2.660	28.28	15.22	153.63
Minimum	2.524	4.81	2.00	115.55
Average	2.622	15.89	7.486	136.36

FREEZING AND THAWING TESTS

As said in a previous paper, the difficulties involved in manipulation and the many conditions which must be considered before conclusions can be drawn from quantitative results of freezing and thawing tests, have apparently had the effect of almost excluding these determinations from reports on building stones. The effect of alternate freezing and thawing may be manifested in three ways: (1) cracks may form; (2) small particles or grains may be thrown off from the surface, occasioning a loss in weight; (3) the cement may be weakened or the grains broken, causing the strength to be materially lessened.

Cracks.— Cracking, as a result of freezing, is seldom observed in the laboratory tests, owing to the careful manner in which the samples are usually prepared.

Loss in weight.— Small particles are frequently shoved off from the surface of a sample which is subjected to alternate freezing and thawing. Where incipient joints occur small flakes are also sometimes loosened by pressure of the freezing water. Many of the grains at or near the surface of sandstone samples become loosened in the process of sawing or hammer dressing. These grains usually adhere to the sample so loosely that they

fall away from the parent mass under very moderate pressure. Loose particles at the surface are naturally more plentiful in the case of sedimentary rocks such as sandstone than they are in the case of igneous rocks or finely crystalline limestone. The loss in weight due to alternate freezing and thawing *will depend mainly* upon the manner in which the samples have been dressed and the kind of stone tested. The experiments which I have performed have demonstrated to my satisfaction that alternate freezing and thawing for a period of thirty-five days results in scarcely more than the removal of the loosened grains or fragments from the surface. Any loss in weight which may be partly accounted for by the manner of preparing the samples does not indicate the extent to which the stone has been injured.

Loss in weight due to freezing and thawing was determined for eighteen samples of granite from eleven different quarries. The loss in weight in these cases did not exceed .05 of 1 per cent. on a mass of about 350 to 360 grams. In the case of limestone, in which twenty-one samples from eleven different quarries were tested, the loss did not exceed .3 of 1 per cent., being, as a rule, less than .1 of 1 per cent. The loss in weight of the sandstone samples, of which twenty-four from twelve different quarries were tested, did not exceed .62 of 1 per cent. and averaged about .28 of 1 per cent.

TABLE VI

FREEZING AND THAWING TESTS

Loss per cent. of weight

	Highest test	Lowest test	Average
Granite and rhyolite: sixteen samples from eleven different quarries	.05	.006	.035
Limestone: twenty-one samples from eleven different quarries	.30	.005	.0753
Sandstone: twenty-four samples from twelve different quarries	.62	.015	.276

Such losses in weight are almost insignificant, and are valuable mainly in showing that the more loosely compacted

sandstone samples have more of the exterior grains loosened in preparation than do the granite, rhyolite, and limestone. It is very probable that had these same samples been subjected to a second period of alternate freezing and thawing, the granite, limestone, and sandstone would have agreed more nearly in the loss by weight.

Loss in crushing strength.—The result of alternate freezing and thawing is more clearly manifested by a decrease in the crushing strength of the rock than by the loss in weight. It is very evident that if a stone having sub-capillary pores is subjected to alternate freezing and thawing for a considerable period, the adhesion of the particles will be weakened and the cement perhaps shattered or broken. This will not necessarily occasion an immediate loss in weight, but must necessarily decrease the strength of the stone. The samples which were subjected to alternate freezing and thawing for thirty-five days were broken in a testing machine to determine their crushing strength. The crushing strength thus obtained was compared with the crushing strength obtained from the samples of fresh stone. With a few explainable exceptions, the crushing strength of the frozen samples of granite was much less than that of the fresh. The crushing strength of the frozen samples from ten different granite quarries was less than the crushing strength of the fresh samples by from 2201 pounds to 13,075 pounds per square inch. In the case of limestone samples from eleven different quarries the frozen samples from eight showed a loss in crushing strength of from 571 pounds to 18,714 pounds per square inch. Among the frozen samples of sandstone from ten different quarries, six gave crushing strength tests which ranged from 326 to 6264 pounds per square inch lower than the crushing strength of the fresh samples. The average loss for all the frozen samples of each kind of rock is given in Table VII. Table VIII gives a comparison between the average crushing strength of fresh and frozen samples, and also the average loss through freezing.

TABLE VII

ULTIMATE STRENGTH IN POUNDS PER SQUARE INCH OF FROZEN SAMPLES

	Highest test	Lowest test	Average
Granite and rhyolite: sixteen samples from twelve different quarries	37,027	9,765	22,875
Limestone: twenty-one samples from eleven different quarries	34,784	5,584	18,267
Sandstone: twenty-four samples from twelve different quarries	9,245	2,116	4,724

TABLE VIII

COMPARATIVE CRUSHING STRENGTH OF FRESH AND FROZEN SAMPLES

	Crushing strength of fresh samples	Crushing strength of frozen samples	Difference, or loss in strength through freezing
Granite and rhyolite: average difference in strength of twenty-three fresh and eighteen frozen samples from eleven different quarries	29,696	22,793	6,903
Limestone: average difference in strength of twenty-one fresh and twenty-one frozen samples from eleven different quarries	25,222	18,267	6,955
Sandstone: average difference in strength of eighteen fresh and twenty-four frozen samples from ten different quarries	5,461	4,453	1,008

These experiments illustrate two points which I have made in the previous discussion: (1) that the results of freezing and thawing can be best estimated from the loss in crushing strength; (2) that the larger the pores, without respect to the percentage of pore space, the less will be the injury from freezing and thawing. There is little doubt but that a stone having a high percentage of pore space, *if completely saturated* with water and frozen, will suffer greater injury than one with a lower percentage. But the conditions under which freezing takes place must be considered before conclusions reached are of any practical value. These conditions include a time element which enters to modify very materially the results. After making this time element as short as the conditions under which the experiments

were performed would permit, it was demonstrated that the strength of the sandstone, which had a high percentage of pore space, was less affected by freezing and thawing than the strong granites and limestones having a low percentage of pore space. It was naturally thought that the Dunnville sandstone, which has 28.28 per cent. of pore space, and consists of relatively fine particles, would experience a greater loss in strength than any of the other rocks tested. The results, however, give evidence that a rock as fine-grained and poorly-cemented as this, with pore spaces which are little greater than sub-capillary size, is but slightly injured by alternate freezing and thawing.

It has been a matter of frequent observation that limestone and marble suffer more by hard freezing immediately after being taken from the quarry than other stones which have a higher porosity. This has usually been spoken of as exceptional, but I venture to say that between limestone, marble, and sandstone, the two former can furnish more examples of injury by freezing of interstatial water than the latter. A reasonable explanation for this result would be that the pore spaces in the limestone are usually of sub-capillary size, while those in the sandstone are mainly of capillary size.

EFFECTS OF SULPHUROUS ACID GAS

Limestone, dolomite, and marble are the only stones which are to any extent injured by sulphurous acid gas. Eleven samples of limestone and dolomite from as many different quarries were exposed for forty-four days to sulphurous acid gas in a moist atmosphere. Some of the pieces of limestone were colored yellow, others were slightly etched on the surface, while many of the samples showed a glistening precipitate of magnesium salts. By washing the samples the magnesium salt was taken into solution and through this the weight of the sample was slightly decreased.

The deterioration of limestone or dolomite in a moist atmosphere laden with sulphurous acid gas is apparently not very rapid. Where deterioration does not proceed very rapidly under

such extreme conditions, in an ordinary atmosphere it would be many years before the gas would have any appreciable effect upon the limestone in the walls of a building.

EFFECT OF CARBONIC ACID GAS

Eleven samples of limestone and dolomite were tested to determine the effects of carbonic acid gas in a moist atmosphere. After treatment for forty-four days there was apparently no deterioration either in weight or color.

EFFECT OF HIGH TEMPERATURE

Few experiments have thus far been performed to determine the limit of temperature which different kinds of stone will stand without injury.[1] It is known, however, that a stone will stand a much higher temperature when heated and cooled slowly than when heated and cooled rapidly.

Samples of granite from six different quarries were tested in a muffle furnace to determine the temperature which they would stand without being destroyed. The samples were all practically uninjured up to a temperature of 1200° F. but most of them were destroyed before a temperature of 1500° F. was reached. Eleven different samples of limestone from as many different quarries were tested and each of them was partially calcined before a temperature of 1400° F. was reached. The eleven samples of sandstone which were tested were mostly destroyed at a temperature of less than 1200° F. although in one instance a temperature of 1500° F. apparently left the sample uninjured.

All the heated samples when struck with a hammer or scratched with a nail emitted a sound very similar to that given off by brick. Planes of lamination were brought out more distinctly as the temperature increased.

The samples of granite cracked differently depending upon whether they were coarse or fine grained. The very coarse grained granite samples broke in a great many places and may be said to have exploded. The cracks were so numerous in one

[1] See "Notes on Building Stones" by HIRAM CUTTING, Montpelier, Vt., 1880.

EXPLANATION OF PLATE I

RESULTS OF CRUSHING GRANITE AND RHYOLITE

The figures in this plate illustrate some of the more perfect cones resulting from crushing the stronger samples of granite and rhyolite. Fig. 1 is a typical result for granite of this class, while Fig. 3 is a typical rhyolite cone. This latter cone resulted from crushing a two-inch cube of granite, which gave a test of nearly 48,000 pounds per square inch. It will be further observed that Figs. 4 and 5 have wedge-shaped apices similar to those illustrated in Pl. IV, Fig. 3.

JOUR. GEOL., VOL. VIII, NO. 6 Plate I

Results of crushing granite and rhyolite cubes.

EXPLANATION OF PLATE II

FIGS. 1, 2, and 3.—These samples illustrate the different forms developed in crushing granite cubes. The one on the left is a typical cone. The one on the right has a tendency toward the wedge-shaped form, while the one in the middle is a typical wedge form. The upper part of this wedge is a sharp ridge from one end to the other.

FIGS. 4, 5, and 6.—These three figures have their apices pointing toward the observer. They are all well shaped cones, in which there has been especially well developed the concentric structure referred to in the text.

JOUR. GEOL., VOL. VIII, No. 6 Plate II

Results of crushing granite cubes.

EXPLANATION OF PLATE III

The figures in this plate illustrate the results of crushing samples of the strongest limestone of Wisconsin. The sample in the lower right hand corner, Fig. 6, gave a crushing strength test of 42,787 pounds per square inch, which is thought to be the highest record obtained for any limestone, dolomite, or marble quarried in the United States. This sample shows, near the apex of the somewhat irregular cone, the concentric cleavage structure, which is typically developed in the granite.

JOUR. GEOL., VOL. VIII, No. 6 Plate III

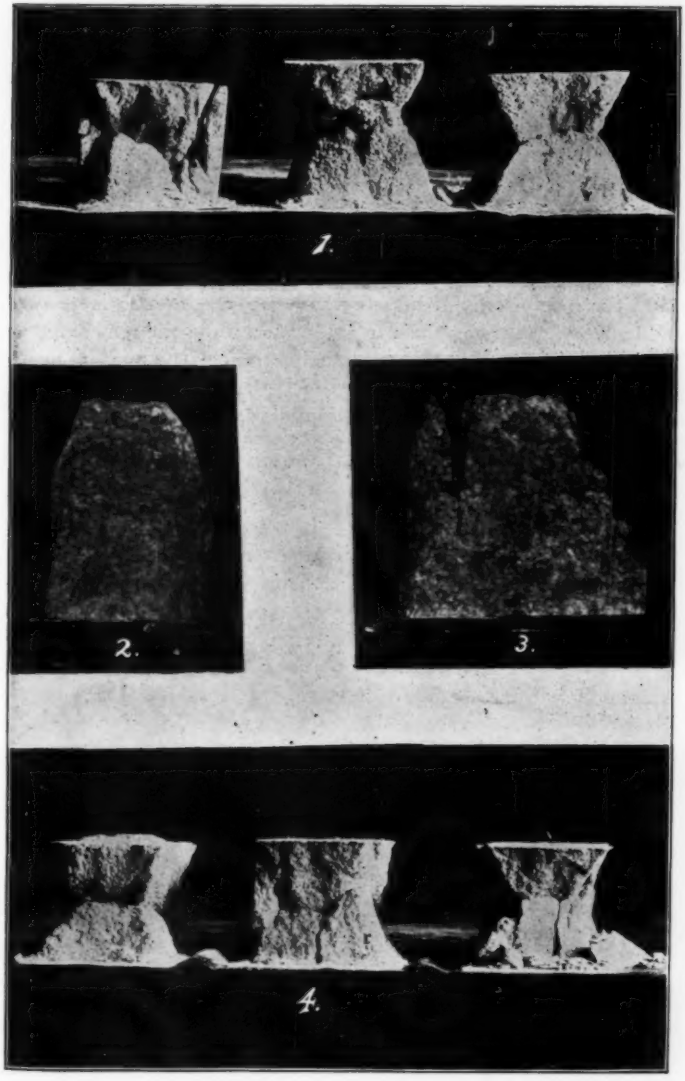
Results of crushing limestone cubes.

EXPLANATION OF PLATE IV

FIG. 1.—Samples of brown sandstone in which the pyramidal forms are well developed.

FIGS. 2 and 3.—Samples of granite. Only the upper wedge or pyramid was developed in each cube. Fig. 2 approaches the conical form, which ordinarily results from crushing granite. (See Pl. II.) Fig. 3 is the typical wedge-shaped form, which often results from crushing granite of medium strength.

FIG. 4.—Samples of brown sandstone in which the pyramidal structure is well developed. These are typical results obtained from crushing sandstone of ordinary strength. It should be observed that the samples which have a low or medium crushing strength are the only ones in which two equally well developed pyramids occur.



Results of crushing sandstone and granite cubes.

EXPLANATION OF PLATE V

The samples numbered 1, 3, 6, 7, 13, and 16 are granite; those numbered 8, 9, 10, and 11 are limestone; and numbers 2, 3, 4, 12, 14, and 15 are sandstone. Samples numbered 5, 6, and 13 were cooled suddenly by immersing them in cold water, while the remaining were cooled gradually. Number 6 is fine grained, number 5 medium grained, and number 13 coarse grained granite. It is simply necessary to direct attention to these samples, for one to see how the difference in grain influenced the manner of cracking.

The limestone samples were partly calcinated. Where the quicklime has been removed the samples have the rounded edges noticed in numbers 9 and 10.

The sandstone samples are, to all outward appearances, uninjured, as shown in samples numbered 2 and 15. The chipping of the corners and edges in numbers 4, 12, and 14 was occasioned by pressing the thumb against the parts broken off, which in spite of the uninjured appearance of the samples, indicates the friable character of the stone after heating to the extreme temperature of 1300°–1500° F.

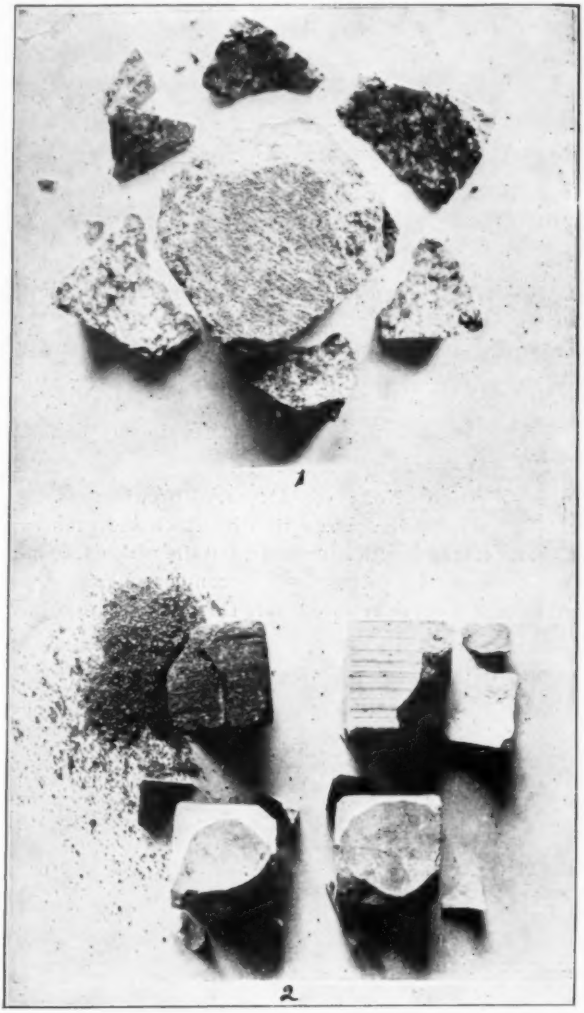
JOUR. GEOL., VOL. VIII, NO. 6 Plate V

Results of subjecting different kinds of stone to high temperatures.

EXPLANATION OF PLATE VI

FIG. 1.—A sample of medium-grained granite heated to a temperature of from 1300°–1500° F., and suddenly cooled by immersing in cold water. This figure is a good illustration of the result of throwing a stream of water on the walls of a burning building, which is constructed out of granite of this texture.

FIG. 2—The sample in the upper left hand corner is sandstone which has become so friable by being heated to a temperature of 1300°–1500° F., that it crumbles when pressed between the fingers. The remaining samples are limestone. They have flaked off at the corners, due to having been quickly cooled from a very high temperature. Such results may frequently be noticed in the limestone walls of buildings which have been destroyed by fire.



Results of rapidly cooling samples of granite, limestone, and sandstone that have been heated to a high temperature.

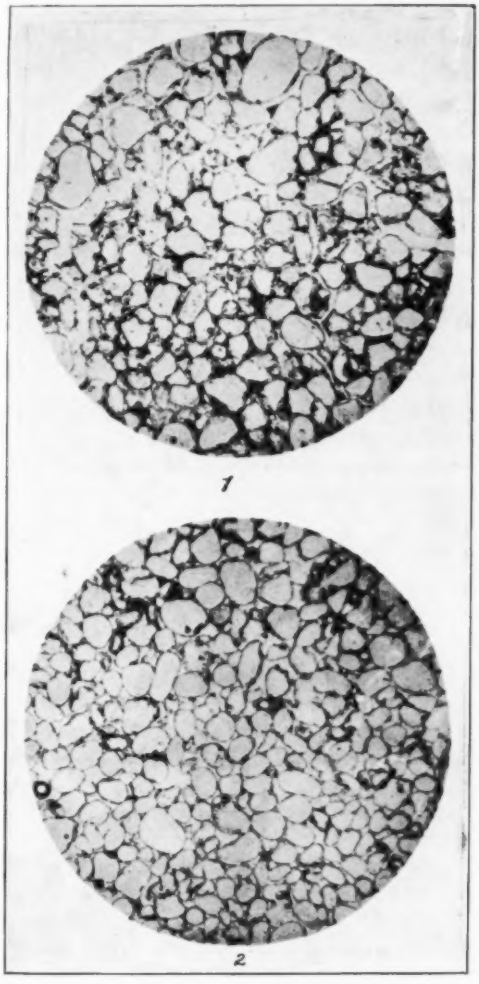
EXPLANATION OF PLATE VII

FIG. 1.—Section No. 4721. (× 12.)[1] Red sandstone from LaValle. This is an excellent illustration of a sandstone in which the grains were originally uniformly well rounded, and later enlarged and cemented with silica. The enlargements are nicely shown in many places in the section. The brown rims of iron oxide which separate the original grains from the secondary quartz are very distinct in the figure.

FIG. 2.—Section No. 4720. (× 12.) Brown sandstone from Argyle. This section illustrates a rock in which the grains are well-rounded and cemented with iron oxide, but in which the individuals have not been generally enlarged with secondary quartz. On account of this the stone is considerably weaker than the one from LaValle.

[1] Magnified twelve diameters.

JOUR. GEOL., VOL. VIII, No. 6 Plate VII

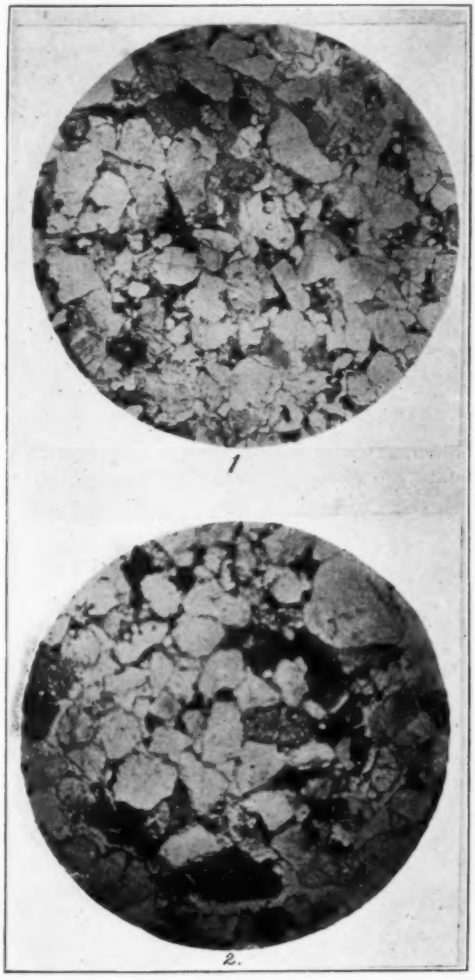


Thin sections of sandstone.

EXPLANATION OF PLATE VIII

FIG. 1.—Section 4719 (× 12). Lake Superior brown sandstone from the Chequamegon Area. This section is composed mainly of quartz and the accompanying figure shows the size, shape and arrangement of the grains. It will be observed that they do not interlock.

FIG. 2.—Section 4714 (× 12). Lake Superior brown sandstone from the Chequamegon Area. The grains are somewhat better rounded in this, than in the preceding section. One will quickly notice the secondary quartz which in many places cements the individual grains together. Occasional grains of feldspar occur among those of quartz.



Thin sections of sandstone.

EXPLANATION OF PLATE IX

FIG. 1.—Section No. 4736. (× 12.) Dolomitic limestone from Duck Creek. This figure is an excellent illustration of the way in which the individuals of the coarser crystalline limestones interlock.

FIG. 2.—Section No. 4726. (× 12.) Dolomitic limestone from Sturgeon Bay. This figure shows the close, compact character of the crystalline dolomites, which accounts for their low percentage of pore space, and partly for their high crushing strength.

JOUR. GEOL., VOL. VIII, No. 6 Plate IX

Thin sections of limestone.

EXPLANATION OF PLATE X

FIG. 1.—Section No. 4733. (× 12.) Berlin rhyolite. This figure shows the exceedingly fine grained matrix and the porphyritic individuals of feldspar, which are characteristic of the rock in the hand specimen. The mica which occurs in small flakes is also nicely shown. The parallel arrangement of the small flakes, which is evidently a cause for the "rift" in the rock, is well brought out. The cracking of the feldspar, referred to in the text, is also seen in this figure.

FIG. 2.—Section No. 4704. (× 12.) Utley rhyolite. Porphyritic crystals of quartz and feldspar and a small portion of the fine, dense matrix are shown in this figure. The compactness of the rock, with the consequently minute pores and low porosity are very evident.

Thin sections of rhyolite.

EXPLANATION OF PLATE XI

FIG. 1.—Section No. 4702 (× 12). Granite from Waupaca. This rock contains a greater variety of minerals than No. 4711. Besides quartz and feldspar there is an abundance of chlorite, epidote, and, in some places, biotite. The individuals are interlocking, but less regular than in many granites.

FIG. 2.—Section No. 4711 (× 12). Granite from Granite Heights. The dark colored parts are feldspar, and the lighter colored are quartz. This section illustrates nicely the close, interlocking character of the different individuals which contributes largely to the strength of the rock.

Thin sections of granite.

of the samples that it broke into fragments not much larger than the individual grains. The granites having medium sized grains flaked off at the corners when cooled moderately fast. The fine grained granite, such as the Montello, developed cracks through the middle of the sample. The different ways in which the granites were cracked and broken are illustrated in Plate V.

In contrast with the limestone and granite, the sandstone was to all appearances little injured by the extreme heat. Samples which were taken from the muffle furnace and allowed to cool gradually appeared to be uninjured, but after they had cooled one could crumble any of them in the hand almost as easily as he could the most incoherent sandstone. In fact, some of the samples when heated to a temperature of 1500° F. became so incoherent that after they had cooled they could scarcely be picked up without falling into sand. A person might be easily deceived as to the injury occasioned by extreme heat on sandstone. The samples often look as fresh and clean as when first quarried and, unless tested with the hammer, one would never suspect that the strength was so largely gone.

In general, the temperature tests indicate that there are few if any stones, whether they be granite, limestone, or sandstone, which will effectually withstand for a moderate length of time a temperature of 1500° F.

MICROSCOPIC TESTS

Thin sections of the more important building stones which were otherwise inspected were examined under a compound microscope. The microscopic examination reveals clearly the texture, composition and finer structures of the rock. These, combined with the field observations, furnish abundant data from which a person familiar with microscopical studies can estimate both the strength and durability of a stone.

The irregular interlocking character of the grains composing the igneous and finely crystalline rocks give evidence of strength which far exceeds that displayed by the sandstones composed of rounded grains which are held together by occasional patches of

ferruginous or siliceous cement. Each sample by itself has peculiarities in texture and composition which either add or detract from the strength and durability of the stone.

Plates VII, VIII, IX, X, and XI, with the accompanying explanations, illustrate the character of several of the Wisconsin building stones and the elements which contribute to their strength and durability.

E. R. Buckley.

Reviews

Glacial Erosion in France, Switzerland, and Norway. By William Morris Davis. Proc. Bos. Soc. Nat. Hist., July 1900; 49 pp., 7 figures, 3 plates.

In this admirable essay Professor Davis gives cogent reasons for modifying his former views relative to the efficiency of glaciers as erosive agents. A gradual change from a former conservative opinion which had been in progress in recent years was greatly accelerated by his studies in the Alps, Norway, and France during the past year. These studies lay along those topographical lines which Professor Davis had cultivated for the past two decades with such eminent success. They centered on the great discordance which he observed between the main and the tributary valleys when the former have been occupied by ice streams and the latter have not, or at least have not been effectively modified by glaciers. The tributaries in such cases have been styled by Gilbert "hanging valleys" because, instead of joining their primaries on well-adjusted normal gradients, they enter high up on the side walls. The tributary streams cascade down an abrupt declivity in entering the main glaciated valley in a manner quite out of harmony with their normal behavior within the tributary valleys above or in the glacial valleys below. Associated with the topographic break between the tributaries and the glacially worn primaries there are contrasted physiographies that point, as it seems to the author, and to the reviewer as well, unequivocally to the origin of the phenomena. In the tributary valleys, although in Pleistocene times they were involved in the general glaciation of the region, in some measure at least, the characteristic configuration of weathering and of water erosion clearly predominates, while in the main valleys, which have been the chief channels of glacial movement, flat bottoms and precipitous sides, bearing the peculiar aspects of glacially worn troughs, prevail. No observant traveler in Switzerland has failed to note the numerous small streams that cascade down the abrupt walls of the glaciated valleys. The numerous falls of Aar Valley, especially

that portion immediately below the Unter-Aar glacier, is a familiar and striking example.

Although these phenomena have long been noticed and some appreciation of their signification has been felt, it remained for a master in modern physiography to see and to set forth their fuller meaning. It is assumed that in the pre-glacial times the tributaries joined the trunk streams in the normal way with well-adjusted gradients, and that the discordance now shown is the result of the superior erosion of the trunk valleys by the glacial tongues that occupied them. The amount of the discordance is, therefore, taken as a rough measure of the superior erosive efficiency of the glaciers. In the Alps this is recorded in hundreds of feet, and in Norway it reaches into the lower thousands, and gives an impressive illustration of the erosive power of glaciers.

There are, however, several qualifications to be applied to this rough measure, and these are rather more complicated, and perhaps more important, than one might apprehend from reading the paper, though they do not seriously affect its method or its conclusions. In the broadening of the main valley by glacial erosion the mouths of the tributaries were cut back and the present points of intersection lie at higher levels than the original axis of the main valley. This is theoretically restored by projecting the gradient lines of the tributaries till they meet in the center of the main valley. For the main purposes of a general view, such as is sought by the paper, it is, doubtless, sufficiently near the truth to project the present lines of the tributary valleys without modification, but in stricter studies it is necessary to recognize the changes which the tributary valleys have undergone while the main valleys were being deepened by glacial erosion.

If unobstructed erosion was in progress in the tributary valleys while the main ones were being excavated by glaciers, the discordance between the two at the close would measure the *difference* in the rates of erosion of glaciers and of ordinary agencies, and a plus correction would be necessary to secure the absolute glacial erosion. During a part of the glacial period the tributary valleys were smothered in a general mantle of ice and suffered glacial modification as well as the main valleys, but not in just the same way. The main valleys lay in the chief direction of ice movement, for they determined it. The tributaries in the main lay more or less athwart the ice movement. They must hence be presumed to have suffered more or less of rasping

down of their rims and of filling up of their axes, and they thus assumed lower reliefs and flatter lines. The projection of their lines thus modified would not accurately represent the true preglacial lines. If the general glaciation sustained a large ratio, dynamically speaking, to the local or valley glaciation, this modification might introduce an error of some moment. As a matter of fact, however, judging from what we know of the general glaciation of the Alps, it probably was not very material. It is less easy to say what may be true of Norway, where general glaciation was much more important both actually and relatively.

In the advancing and retreatal stages of the several glaciations another group of influences came into play. The main valleys were filled by glacial tongues which more or less effectually blocked up the mouths of the tributaries, checked erosion in them, and induced filling, as may be seen in many such valleys today in the Alps, in Greenland, and elsewhere. The valley occupied by the Märjelen See may be cited as a familiar and striking example. While the mouths of the tributary valleys were thus blocked up, their rims were being degraded and a change was thus being wrought in their configuration. The effect of this class of action was to give the tributary valleys not only gentler declivities than they had preglacially, but gentler even than they would have acquired in the natural degradation of the basin had it remained open and free from ice throughout. The result may be styled a premature maturity, for it was not strictly normal to valleys at such positions in the general drainage system. It was a maturity of a local nature hastened by the establishment of a transient base-level at the mouths of the tributaries by the obstructing ice.

This special phase of the reshaping of the tributary valleys, being of the erosive type and being aided by the special climatic conditions of the time and by the high declivities of the valley sides, doubtless quite rapidly removed the signs of the previous subduing effects of general glaciation and restored an aspect resembling the preglacial one without being such, and hence made it difficult to distinguish this pseudo-maturity, if it may be so called, from such degree of maturity as had been attained in preglacial times, or, if you please, such an ideal stage of maturity as would have been reached by subærial erosion had not glaciation interfered. A restoration of the preglacial conditions of the main valley based on the lines of this pseudo-maturity of the tributaries would obviously involve error. Its amount depends on

the value of these phases of action, and that in turn is dependent on the duration and complexity of the glacial period.

A strict discussion is constantly vexed by the question whether the competency of the glaciers to erode is to be measured by the absolute amount of work done by them during their existence, be it longer or shorter, or by the ratio of the work they do to that which would be done by the usual erosive agencies in the same area and for the same time. Are we trying to determine the absolute or the relative? The latter is probably the truer basis of estimation in general, but both have their special values.

In the case in hand, such degradation of the tributaries at their mouths as took place during the period of glaciation lowered the base of reference by which the glacial erosion is measured, and a plus correction is required to give its absolute amount as already indicated. The lowering of the gradients and the premature flattening of the tributary basins, if uncorrected, leads to an erroneous projection of lines across the valleys and requires a negative correction in absolute measurement, and a more complicated and serious correction in relative measurement.

These suggestions do not cover the whole case, but they go as far as is perhaps permissible in a review, indeed, not unlikely farther than is warranted in the review of a paper based on fugitive studies that do not claim an exhaustive character. The importance, or otherwise, of the qualifications suggested depends much upon the duration and the fluctuations of the glacial period and the ratio of the general glacial action to the local valley phases.

If there is any reference in the paper to similar discordances between main valleys and tributaries not in any way connected with glacial erosion, it escaped the eye of the reviewer. Such cases of declared form exist and might naturally be expected to find at least passing recognition in a paper founded on discrepancies of this kind, the more so because in this neglected class also the main valleys are discrepantly broad and deep and the tributaries cascade down into them not unlike those described in the paper, though much less strikingly. Probably the neglected case has little application to the Alpine valleys discussed, and perhaps only an unimportant application to those of Norway. The case referred to arises from changes of drainage, whereby large volumes of water are thrown into valleys that had previously carried much less; such cases, for example, as the Upper

Ohio and the Upper Missouri. In these cases the great accessions of water have broadened and deepened the main channels out of all concordance with their tributaries. These at some distance back from the trunk streams run in their old valleys slightly modified, but as they approach the main valley, they rush down through new gorges, not, indeed, as steep and picturesque as those of the Alps or of Norway, but of like type. These have for some time been distinctly recognized, and are in constant use as working criteria in discriminating earlier and later systems of erosion, involving changed conditions. (See "Further Studies of the Drainage Features of the Upper Ohio Basin," Am. Jour., Sec. XLVII, April 1894, pp. 261–262.)

It seems to have been demonstrated that in Norway the glacial summit was some distance east of the present topographic divide and that hence the Norwegian valleys were called upon to carry away an amount of drainage greater than that which normally belonged to them in preglacial times. This took the form of ice at certain stages, and of water issuing from the edge of the ice field at other stages. How far this may have contributed to the observed result it is hard to guess without knowing more of the detailed history of the glacial period in that region, but it illustrates the connection of this mode of origin of discrepancies between trunk streams and tributaries with similar discrepancies of a true glacial origin. It is probable that even in the Alps, partly by topographic modification and partly by superior condensation, glaciation has concentrated an exceptional amount of drainage in the trunk valleys.

It is not probable, however, that any or all of the modifications herein suggested, or any others, seriously affect the representative truthfulness of the rough estimate of the superior erosive power of glaciers founded on discordance between the tributary hanging valleys and the glaciated trunk valleys. The paper is a valuable contribution to the doctrine of glacial erosion, and is likely to be the more influential with those holding opposite views because it comes from one who has heretofore held a conservative position on the subject.

The reviewer does not, on first reading, sympathize fully with the effort of Professor Davis to extend the analogy of river erosion so unreservedly to glacial work as done in the paper. The analogy is truer in gross externals than in refined analysis. A river erodes by virtue of its pressure and momentum, scarcely at all by rigidity. Very largely its work is done by the striking force of particles driven rapidly

against the valley walls and bottom, or against each other. This is largely true even of the pebbles rolled on its bottom, as anyone may see by examining the nick-marks that cover their surfaces and that sharply distinguish them from glaciated pebbles, or by critically comparing a waterworked surface with a glacially worn surface.

On the other hand a glacier does its work by virtue of its rigidity and pressure, and scarcely at all by its momentum, for its velocity is very low. A river with the same velocity as a glacier would be almost absolutely inert as an abrading agency. In the judgment of the reviewer no one is entitled in the present state of evidence to assume that the laws of fluids control the action of glaciers except in external similitude, which is due to the fact that gravitation is the dominant factor in both cases. In convenient and popular exposition the similitude has many advantages, but in framing scientific doctrine and nomenclature, and still more in mental procedure, it is attended by danger. It is doubtless as important to avoid the similitude in critical work as it is permissible to use it in easy exposition.

T. C. C.

Bartholomew's Physical Atlas: An Atlas of Meteorology. Vol. III. A series of over four hundred maps. Prepared by J. G. BARTHOLOMEW, F.R.S.E., and A. J. HERBERTSON, PH.D., and edited by Alexander Buchan, F.R.S. Under the patronage of the Royal Geographical Society. Edinburgh, 1899.

This is the first volume to appear of what promises to be an epoch making work in scientific geography. The entire field of physical geography is to be covered by seven volumes. The plan was furnisht by the famous *Physikalischer Atlas* of Berghaus, tho the field is vastly extended, and it will make a work when completed, perhaps ten times the size of the German atlas.

This great venture is preparing under the direction of J. G. Bartholomew, revised and edited by a corps of eminent specialists, in volumes as follows:

I. Geology — Sir Archibald Geikie.
II. Oceanography — Sir John Murray; and
Orography — Professor James Geikie.
III. Meteorology — Alexander Buchan,
IV. Botany — Professor Bayley Balfour.

V. Zoölogy — P. L. Sclater.
VI. Ethnography — Professor A. H. Keane; and
Demography — Professor Elisee Reclus.
VII. Cosmography — Professor Ralph Copeland; and
Magnetism — Professor C. G. Nott.

It is now about half a century since the appearance of a great English work along these lines, that of Dr. Keith Johnston, based on the *Physikalischer Atlas* of Dr. Heinrich Berghaus (1837–1852). The original German publication is justly regarded as a landmark in the history of geography, and has been kept at the forefront of high art in cartography by his nephew, Dr. Hermann Berghaus, who brought to his aid some of the most famous German scholars, such as Hann, Neumayr, Zittel, and others. This is the work which has been such an inspiration to the students of geology and geography in the present generation, and this atlas it is which has furnisht the plan for the greater Scotch work now in preparation. To quote from the prospectus:

Recent years have marked a great and rapid development in the field of scientific geography. The additions to our previous knowledge have been numerous and important, but they are scattered throughout hundreds of publications, in various languages, they are difficult to find, and known only to specialists in each department. Hence there is a need for a work embodying in concrete and graphic form a digest of all this scattered material — a new physical atlas.

So some years ago the enterprising Scotch firm obtained copyright privileges on the material in the Berghaus plates, and planned at much larger work, one of over two hundred plates, compiled from sources liable to be of more immediate interest to English and American students, getting the heartiest coöperation from the world's greatest specialists along all the desirable lines; ten years have already gone to the preparation of the most comprehensive work of the kind ever attempted. The cost of production alone will reach a half million dollars.

Curiously enough meteorology, the youngest of the physical sciences, is so far advanced in the accumulation of data from very wide areas of the earth's surface, that it is in the most forward condition of all as to the possibility of charting complete data. Mr. Alexander Buchan makes this rather startling statement:

If the present state of the science of meteorology as regards the geographical distribution of results be compared with that of the other sciences such as

geology and the biological sciences, it stands second to none. None of these sciences can show such a world-wide distribution of precise results as are collected in this atlas of meteorology, in illustration of the geographical distribution of temperature, pressure, humidity, cloud, rainfall, and movements of the atmosphere, with illustrations of their influences over, and interrelations with, each other.

Dr. Hann's *Atlas der Meteorologie* was the first attempt to chart systematically the data of the science. His atlas, as found in Berghaus, has twelve plates, giving about sixty maps. And, altho this has been brought down to 1887, there has been a very great advance in all lines of the science since then, and the time is ripe for a more complete publication. A mass of widely scattered observations from all over the world is now charted for the first time.

The 400 maps of this atlas of meteorology are groupt under the two heads of Climate and Weather. The climate maps summarize the great mass of observations, first for the whole world, next for more detailed study of regions specially rich in observational data. There are monthly and annual charts for the elements of climate—temperature, pressure, winds, cloud, sunshine, and rainfall. The weather maps show the most characteristic weather types for given periods over defined regions.

Preceding the charts there is a general introductory article, and a special discussion of each chart. This will be of the highest value to students of climate and the weather. Appendices give complete lists of all the meteorological services, with all the stations and publications. The frontispiece consists of a graphic charting of the areal distribution of observations over the earth, in which India, Europe, and the United States stand out conspicuously in their dark shading. The volume closes with a glossary of terms, and a critical bibliography, classified for all lines of research in the subject, both of which will be very helpful.

The magnitude of the undertaking of the preparation of these charts, and the accuracy we are here dealing with will be better realized when some plain statement of the figures is made. The total number of meteorological stations is, in round numbers, 380 of the Order I; 2620 of the Order II; 6600 of the Order III, and of Rainfall, 19,400; total, 29,000; special stations for crop reports will bring the grand total up to about 31,000.

The general temperature charts are based upon fifteen years' observations from 1539 stations. The general pressure charts from fifteen years' observations at 1280 stations. These reports are the summaries of about 17,000,000 observations for temperature, and about 14,000,000 for pressure, and this is excluding all observations at sea.

The charts of the first part under the general heading Climate, are classified under the headings:

I. Isotherms.
II. Isobars and wind arrows.
III. Isotherms and Isobars month to month.
IV. Isohels, the year's sunshine for Europe and North America.
V. Isonephs, distribution of cloudness over the globe.
VI. Isohyets, annual, seasonal and monthly rainfall over the globe.
VII. Maps of hyetal regions and seasonal distribution.
VIII. Isobars and Isohyets; rainfall as related to pressures.

The second part on Weather, has charts classified as:

I. Abnormally cold and hot seasons and months.
II. Pressures as related to wind in type storms.
III. Pressures as related to types of wind and weather.
IV. Storm tracks and storm frequency.
V. Type deviations from normal pressures.

The first chart in the volume shows the world's isotherms on Mercator's projection, in which the relief of the land is shown by line shadings in black. Contours of 600, 3000, 6000, and 12,000 feet are shown, and similar contours in the oceans represented by fine dotted lines. Even the little 3×6-inch insets show all highlands over 3000 feet by shading. This plate and No. 11, the world's isobars, are equally beautiful, and are the finest plates in the book. It will be no exaggeration to say that no more beautiful plates have ever been engraved. They are magnificent in accuracy, neatness, completeness and beauty of engraving, nor are the lesser maps less beautiful, they are merely smaller, and chart less complex data as a rule. One is struck, too, by the artistic range of coloring. The tints show with a sufficient contrast the varying values of the data charted, yet there is not a harsh note in the whole book.

Two of the most beautiful plates in the book are the charts of the monthly isotherms of the British Isles, and another of the monthly isobars and isohyets.

In all the maps the English measurements are given, and in each case their metric equivalents — the pity of it, that we need to record in two systems!

It almost seems like caviling to offer any criticism on so sumptuous a work. But there are some shortcomings. In only one case is the projection used named; it would have been an agreeable addition, had the projection been specified for all maps of lesser area, and in all such maps a horizontal scale should be given, either in arithmetical ratio, or by linear representation of miles and kilometers. There is scarcely a scale in the book.

In all maps of isohyets the very important element of altitude, it would seem, is almost a necessity for the proper interpretation of the rainfall, yet on Plate XXI, the principal plate of isohyets, there is no attempt to show altitudes, even in the larger areas of Europe and the United States. The lack of contours and the scale in such insets as Jamaica, Japan, Java, and Mauritius is a serious fault. Even in Plate XXIV in the large scale map of isobars and isohyets of the United States and Canada, only the one contour of 3000 feet is shown. Here, far more than in the general maps of Plates I and II, are the several contours needed. It may be, of course, that in some cases, for example, the India map, the relief was omitted to prevent overloading. And true it is, that with all the mass of data entered in these maps, there is never in any of them a lack of legibility.

But after all the flaws are found, they are not very serious, they are mere spots on the sun. The work will long stand as a monument to very high ability in meteorology and cartography.— J. PAUL G.

Mineral Resources of Kansas, 1899. By ERASMUS HAWORTH, Univ. Geol. Surv. of Kansas, Lawrence, May 1900; pp. 67, 4 plates.

This is the third of the annual bulletins on the mineral resources of the state which the University Geological Survey of Kansas is issuing, and is worthy of note as a laudable effort on the part of an educational institution of high grade to convey to the people, without distinction and without charge, commercially valuable information gathered under scientific auspices. Is is one of the many current indications of the breaking down of the narrow limitations that have so long hedged in the traditional institution of learning to its infinite

harm, and of the broadening and elevation of the functions of universities in the true sense of these adjectives, for an institution is broad in proportion to its contact with the full range of serious thought and with all classes of its natural constituency, and it is elevated in proportion as it is really useful, the notions of the leisure classes to the contrary notwithstanding.

The general summary shows an annual production of nearly 39 million dollars of which, however, a part appears to be the smelting and refinement of ores mined outside the state. The record shows that all the mineral industries felt the impulse of the country's general prosperity. The coal production reached a value of over five million dollars. The plaster, hydraulic cement, clay, salt, and stone industries all exhibit marked advances. Altogether it is a good showing for a state whose great industry is agriculture.

T. C. C.

Results of the Branner-Agassiz Expedition to Brazil.

I. *The Decopod and Stomatopod Crustacea.* By MARY J. RATHBUR. 23 pp., 1 plate.

II. *The Isopod Crustacea.* By HARRIET RICHARDSON, 3 pp., 4 figures.

III. *The Fishes.* By CHARLES H. GILBERT, 23 pp. 1 plate.

IV. *Two Characteristic Geologic Sections on the Northeast Coast of Brazil.* By. J. C. BRANNER, 17 pp., 5 sketch maps and sections, Proc. Wash. Acad. Sci., August 1900.

Nos. I, II, and III relate to existing forms of life, and belong to that realm of current geology which we conveniently, and doubtless wisely, leave to the zoölogists.

No. IV gives in as much detail as field circumstances would permit two sections opened by railways running from the coast toward the interior, and traversing the border formations somewhat nearly normal to their strike. The section along the Bahia and Minas Railway lies at about 18° S. Lat., and that along the Alagôas Railway between 9° 20′ and 9° 40′ S. Lat., the two sections being about a thousand kilometers apart. They show essentially the same structure : a series of relatively young sediments lapping back over old crystalline rocks. The age of the sediments is open to question, and the problem is regarded as too large for specific discussion in the paper. The evidence is thought to point to the following conclusions :

1. The Bahia basin, formerly referred to the Cretaceous, is probably either Eocene Tertiary, or Laramie.

2. The parti-colored beds along the coast, formerly referred provisionally to the Tertiary, are the same as the Bahia Eocene.

3. The sediments of the Alagôas section are of fresh-water origin, like those of Bahia.

4. No fossils have been found in the section along the Bahia and Minas Railway, but it seems probable that these beds are the southward continuation of the Bahia beds.

The crystalline series next back of the sedimentary beds consist mainly of quartz-monzonites (gabbros) granites and gneisses, the first having a notable development. The Bahia-Minas section ends in mica and other schists much faulted, wrinkled, and cut by veins, and much more deeply decomposed than the quartz-monzonites.

The contribution is doubly valuable in that it bears on the evolution of a continent that has played a peculiar and interesting part in geologic history, but which is as yet too little known to be interpreted with precision or satisfaction. The generosity of Agassiz, as well as the devotion of Branner, in securing it are to be gratefully recognized.

T. C. C.

Progress of Geological Work in Canada During 1899. By HENRY M. AMI, Can. Rec. of Sci., Vol. VIII, No. 4, July 1899.

Contrary to the natural interpretation of the title this is a list of works relating to Canadian geology published during the year 1899 through various avenues, and embracing private as well as official works. It will be found helpful to working geologists.

C.

Descriptive Catalogue of a Collection of the Economic Minerals of Canada, Paris International Exhibition, 1900.

This is somewhat more than a simple descriptive catalogue of the minerals exhibited, as it contains notes relative to the modes of their occurrence and to the industrial operations connected with them, when these are important, as well as other incidental information which gives the catalogue value as a book of reference.

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